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OF THE SOCIAL SCIENCES

GIANCARLO BARBIROLI

THE DYNAMICS OF TECHNOLOGY

A Methodological Framework for Techno-Economic Analyses

SPRINGER SCIENCE+BUSINESS MEDIA, LLC

THE DYNAMICS OF TECHNOLOGY

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SERIES A: PHILOSOPHY AND METHODOLOGY OF THE SOCIAL SCIENCES

VOLUME 25

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THE DYNAMICS OF TECHNOLOGY

A Methodological Framework for Techno-Economic Analyses

by

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To Costanza and Virginia

I dedicate this work as a sign of my constant efforts over the years in pursuit of critical knowledge, independence, and equity; however challenging a commitment to these values may prove, I encourage my beloved daughters to follow this road with perseverance and fortitude, in line with my father's legacy.

Contents

INTRODUCTION

Technology is taking on an increasingly central and determining role in society, and can provide contradictory results: wealth on the one hand, but also unemployment, environmental imbalances and other social problems on the other.

Manufacturing techniques and production organization are chosen in every country based mainly on the specific needs of the companies, while the real needs of each population are often quite different.

Already, in order to prevent all forms of technology from becoming increasingly "invasive", towards both the natural supply of resources and the specific — though highly differentiated — needs of humanity, technological paths must be identified and followed which are capable of making the various needs compatible, from the standpoint of sustainable development, the conservation and increase in value of natural resources, and the quality of development. This will become increasingly important in the future.

This goal is undoubtedly ambitious and difficult to achieve; however, evidence of the problems caused by generalized, uncontrolled use of technology, all over the world, leads us to believe that intense efforts must be made to achieve this aim. If not, humankind runs the risk of an irreversible degradation of the most important aspects of economic development and its quality. Within this framework, those companies that produce goods and services obviously occupy a central, active role, which they must play with a view both to competitiveness and overall qualification and to contributing to the objectives of sustainable development.

Therefore, from this standpoint, the choice of production paths, technologies and management criteria is becoming an increasingly complex and difficult one for both public and private companies.

On the other hand, the advances in scientific and technological knowledge have become increasingly rapid and intense, to the point that everyone has an increased number of possible alternatives.

Expansion of the range of available technologies is the main goal that technology policy must set, for obvious reasons: the more technologies that are available in each homogeneous production situation, the greater the chances are of selecting the most appropriate one to provide competitiveness and overall qualification to the companies that adopt it.

This condition holds in every field: from the extraction/processing of raw

mineral and energy goods to the production of foodstuffs, instrumental goods and durable goods.

It should be emphasized that adopting technologies that provide advantageous results for the company and the community — both in the medium, long and very long term — requires a considerable change in the "economic culture and sensitivity" of those in the field and public authorities on the one hand, and just as considerable a change in demand on the other.

The change in economic and industrial culture may in turn be made possible by the expanded knowledge in every field which, organically and systematically connected, provides first a complete reference overview in which to insert choices, then global data on the effects that such choices may create at every level; and finally, operative information on how to apply them economically.

This volume intends to provide, systematically, methods and models capable of critically analyzing the manifold aspects related to technological dynamics, and to arrive — at times *ex post*, at times *ex ante* — at assessments regarding both the economic results that may be achieved anywhere with the innovations and diffusion of technologies in industry, and how they can be applied.

For this purpose, the book describes and critically evaluates conceptual and quantitative methods and models — some already familiar from economic literature and practice, others original and developed here for the first time — which seem capable of satisfying this objective.

There are a number of distinctive features of the volume, but the most important are definitely the relationships between technological dynamics and knowledge, technological dynamics and production structure, and technological dynamics and sustainable development.

As far as the relationships between technological dynamics and knowledge are concerned, it should be emphasized that each technological advance is conditioned by knowledge in all of its aspects, which, however, is not simply an "assembly of information", but the result of a more complex process which the innovator must prepare and implement in order to elaborate and refine the information, adapting it to his own culture and business aptitudes/background, in order to draw stimuli and directions for innovating. Thus those who innovate must not only continually gather the broadest ranging information on advancement and progress achieved everywhere, but also process and adapt this information to their own situation and convert it first into ideas and then into applications. In this sense, the innovator irre-

versibly enters the "innovation culture", which is a pattern of economic behaviour, lasting and effective.

Within this context, the volume highlights the fact that the production of ideas, and thus of innovative knowledge can no longer come solely from the traditional structures and circuits, but requires the availability of new structures which create the conditions for technological and scientific advancement, thus for innovation.

Modern and original structures have already set up in this way; they are generally known as "technopolis", where "technology transfer and industrial liaison centres", "business incubators", "business and innovation centres", "scientific parks", and "technological poles" work separately or together.

Each of these is made up of companies or centres — private, public or mixed — that perform specific functions, separately and/or together, and always in a dynamic and innovative fashion, as shown by the number of successful experiences in industrialized countries. The results show that without such qualified structures, innovation cannot be achieved and systematically and positively managed.

As far as the relationships between technological dynamics and production structures are concerned, these have become increasingly close and yet dynamic, to the point that they condition choices and results in every field.

The role played by business systems and networks in overall technological progress and economic results is especially emphasized, since every production activity interacts with many others, increasingly closely, while still offering increasing internal and external flexibility at every level, and even when divided by large distances.

Basically, the decisive importance of "non-competitive relations" between companies, both on the companies themselves and on the overall economy, is highlighted; this entails a vision of technology as a "system", and not merely as a "production function".

Concerning the third main theme of the volume — relationships between technological dynamics and sustainable development — analyses and assessments carried out on highly significant situations throughout the world — from the major raw materials to large industrial productions, from overall economy to the environment — indicate a strong necessity to follow technological paths that are innovative but also capable of providing positive results for humankind as a whole, and which do not compromize the quality of current development nor the expectations of future generations.

Since it has been found that many manufacturing techniques have caused serious or irreversible damage to natural and environmental resources, unemployment, the quality of living areas, we must first identify and then adopt/spread those manufacturing techniques that respect the needs related to the qualifying objectives of sustainable development, and at the same time provide the companies that adopt them with positive economic results.

Considering that each technology has positive and negative aspects, it follows that it becomes increasingly essential to open up new technological paths, specific and with a growing "sustainability". In this light, the modern "paths and places" of innovation take on an even greater strategic importance, as they are the only ones able to quickly and incisively contribute to opening up and developing adequate technological paths, within the framework of an increased technological pluralism. For example, these would create new frontiers in the field of raw and artificial materials.

Certainly, from this angle, the progress and qualitative improvement of technologies must be accompanied by a corresponding progress and qualitative improvement of business functions, especially their organization and management, and a substantial change in the demand and habits of people towards consumption.

Here again, knowledge becomes the determining and qualifying factor in these necessary transformations.

This book is divided into nine chapters, organized into a coherent whole.

Chapter One deals with the major characteristics of technologies and their evolution: from how they are manifested to their distinguishing features, especially intrinsic properties, relationship with employment, scale effects; these distinguishing features contribute, together with others, to a full understanding of the concept of "technological replaceability". Types and forms of technology and the characteristics of technological appropriateness are also highlighted.

Chapter Two explains the forms in which innovative and diffusive cycles occur and the procedures of technology transfer, and also critically handles the various indicators of the intensity and speed with which technology transfer takes place.

Chapter Three considers the central role of knowledge in innovation, and how information is processed to make it useful for innovative purposes. In addition, it examines in depth the topic of the "paths and places" of innovation (technopolis), their arrangement and functional differentiation: technology transfer and industrial liaison centres, business incubators, business and

innovation centres, scientific parks, and technological poles. Advanced "technopolitan" experiences and those of incubators in some industrialized countries are also described and discussed.

Chapter Four focuses on new production systems and technologies — cleaner production technology, group technology, cell production, flexible systems, just-in-time production — to provide a concise state-of-the-art of the main technological achievements and related issues. It also briefly analyzes production structures in the light of decentralization and non-competitive relationships between businesses, with emphasis on production agglomerates and networks, to identify the real situations where technological dynamics appear.

Chapter Five deals with the efficiency of production processes, with the purpose of providing quantitative indices for measuring the several aspects of processes perfomance, which can be useful both to compare different situations and to identify weak points.

Chapter Six draws a correlation between technological dynamics, product quality and total quality, to highlight the relationships between product quality and value, quality and productivity within each production activity.

Chapter Seven examines and critically discusses the complex and multidimensional economic effects that technologies cause in their innovative and diffusive stage; in particular, on resources and raw materials, mass productions, economic systems, the ecological system. The topic of duality between technological and economic development is then emphasized, within the broader topic of sustainable development, and an innovative line on this topic is proposed in order to positively contribute to developing its theory and application.

Chapter Eight deals with methods for improving the economic assessment of production activities and the related technologies; some methods concern the productivity of the businesses themselves, such as feasibility studies and cost engineering analyses, while others consider compatibility with the environment and with other economic activities. Moreover, a method for assessing the strategic value of technologies is presented, together with some models for analyzing competitiveness/coexistence between technologies, which are considerably important from the standpoint of identifying the most appropriate technologies to satisfy the needs of companies and society, and which economic conditions can make some stand out over others.

Finally, Chapter Nine traces an outline of technological policy, necessary in order to encourage the achievement of the ambitious goals that must be

set in a society that aims to reconcile its needs with those of companies, and which aims to reconcile the needs of current and future generations. Special emphasis is given to the criteria, guidelines and economic policy instruments that must be implemented to guide technological evolution in pursuit of the aims of sustainable development within new economic targets and hierachies of technologies and products.

The approach followed in organizing this volume is an interdisciplinary one, in the sense that it uses analytical methods typical of various disciplines, but in order to arrive at economic conclusions, assessments and generalizations. In short, it may be defined as technical and economic.

This approach has been used by the author in a number of studies carried out in the past, which have led him to develop, propose and concretely apply methods and models in various fields, some of which appear in this book. These studies have also been constantly accompanied by others of a strictly scientific and technical nature, mainly for the purpose of reinforcing preparation and the objective and quantitative logic, in consideration of the increasingly intertwined relationships between the various parts of the circuit: science – technology – economy – ecology.

This volume is designed for use by economists, business executives, policy-makers, but also designers and technicians who may find it useful to refer to this type of technical and economic approach, which is not strictly limited to business aspects.

* * *

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Chapter 1

FEATURES OF TECHNOLOGY AND TECHNOLOGICAL DYNAMICS

1.1. TECHNOLOGY AS A PRODUCTION FUNCTION AND AS A SYSTEM

Conceptually, technology has been defined as a sequence of operations making it possible to adapt original materials to obtain products with their own features, different from those of the raw materials: this leads to the use of production factors according to specific procedures, which determine the result in terms of both quantity and quality.

From an economic standpoint, technology may be considered either as a production function or as a system of variables.

A "production function" is a function that expresses the physical relationship existing in the most efficient technical combinations between product (output) and the factors used in production (input).

The study of production functions, to which we refer (Frisch, 1966), is a way of discovering the links between the various factors of production, the flexibility and possibility of substitution among them, and to find out how it is possible to vary the use of factors in both qualitative and quantitative terms.

The number of factors necessary in order to obtain one unit of product is defined as the "technical coefficient". In order to achieve economic efficiency, a given quantity of a product must be obtained with the optimum use of production factors.

The entity of the individual production factors is always technically variable.

Although extremely simplified, it may be established that, given the prices of the various production factors, it is possible to identify the optimum combination of production coefficients as the one allowing the same unit of product to be obtained at the lowest cost.

A production function may be formulated either analytically (through more or less complex mathematical formulae) or numerically (using tables), or graphically (through function diagrams).

A significant example is represented by the study of conversion yields of the gaseous nitrogen-hydrogen mixture for the production of synthetic am-

monia. It is well known that the process which, after the chemical equilibrium studies carried out by Le Châtelier, was first realized on an industrial scale in Germany in 1913 following research by Haber, is extremely important, since it makes it possible to fix the atmospheric nitrogen, and thus use it as a raw material in order to obtain nitrogen compounds (mainly fertilizers).

The synthesis reaction between nitrogen and hydrogen (in a ratio of 1:3) for the production of ammonia is an equilibrium reaction, whose yield is a function of various factors including temperature, pressure, concentration of the reagents, catalyst activity, and flow velocity of the gas on the catalyst (or contact time).

In order to study the yield variation (thus the amount of product that may be obtained by the combination of factors that take part in the production cycle), it would be necessary to take all variables into account simultaneously.

The study of a technology through the production functions makes it possible to identify the most efficient combinations among the factors used, but is strongly limited in that it does not provide functional measurements of the technology, of the properties of the products obtained, the internal and external implications it leads to, all of which are essential aspects of its effectiveness, as well as its efficiency (Şahal, 1981).

Technology as a "system of variables" — which become complex components of evaluation and decision-making, since they are interrelated — makes it possible to acquire economic elements similar to those of the production function, but also technical-engineering and qualitative elements in reference to the process, the factors used and the products obtained.

Indeed, the economic success of each specific way of production and the corresponding products depends on a number of factors, for each of which it is difficult to determine the weight, especially when changes are made.

Since the construction of a production system inevitably involves the use of all of the technical and economic parameters that take part in a process, similar to the logic of production functions, all interrelations must be set up in order to have a broad overview of the links, useful to analysts and technicians at every level (Barbiroli, 1995).

The systems view of technology is appealing in many respects. First, the functional measures of technology have a very clearly defined meaning and can be objectively measured. For example, the thermal efficiency of an electric power plant can be unambiguously defined as the ratio of the electrical output to the total thermal output of the fuel. It can then be expressed either

directly as a ratio or in terms of an inverse measure, such as the plant heat rate; that is, the amount of fuel in British thermal units required by a plant to produce one kilowatt-hour of electricity.

Second, functional measures of technology are of far more practical value for engineering and managerial purposes than are, for example, the estimates of the neoclassical production functions. This is because the most useful variables in industrial research activities are seldom of a purely distributional or economic nature. Rather, they generally tend to be control oriented. As an example of this, we find that the focus of R&D activity in the transport of crude petroleum by pipelines is typically on reducing the total cost of pipeline construction and control of the oil flow by means of a change in "line diameter", "horsepower", etc., rather than on reducing the cost of capital or labour as such. More generally, functional measures of technology are closely related to the actual objectives of innovative activity, a point so obvious that it is often overlooked.

Third, functional measures of technology make it possible to take into account both major and minor innovations and to assign appropriate weights to their importance according to a certain common denominator. An example may help to make this clear. The development of farm tractor technology has been made possible by a host of innovations, such as the frameless or unitary form of construction, the power takeoff, pneumatic tires, the three-point hitch and control system, hydraulic lift, enclosed transmission, twin-disc clutch, removable cylinder lines, antifriction bearings, power steering, and torque amplifier. It is not easy to assign specific dates to any of these. The case of the power takeoff, cited earlier, is one example of this problem. As another example, the relatively perfected form of the three-point hitch developed in 1938 was the result of more than 17 years of cautious experimentation beginning with the design of an international tractor plough. Nevertheless, its development is still continuing. The essential point of these examples is that any attempt to assign a specific date to the origin of an innovation is bound to be unreliable. Furthermore, numerous difficulties arise in distinguishing between an innovation and a minor variation in technology. Even if a list of innovations can be agreed upon, assigning weight to each of them according to some chosen measure of their importance remains a difficult task. In short, as has already been noted, any conceptualization of technology in terms of the number of relevant innovations is fraught with numerous difficulties. However, when advances in technology are measured in terms of variables such as horsepower-hour per gallon of

fuel used, ratio of drawbar horsepower to belt horsepower, or horsepower-to-weight ratio, not only does it become possible to take into account the various underlying innovations, but also the innovations themselves are evidently weighted according to their contribution to an objectively measurable characteristic of the phenomenon under consideration. For example, the chosen measure of fuel-consumption efficiency of farm tractors is an appropriately weighted measure of both major innovations, such as the successful use of pneumatic tyres, improvement in the quality of fuels, and minor innovations, such as the use of more durable valve, piston, and ring alloys (leading to an increase in the compression ratio, thereby improving the utilization of fuel) and of diffusion effects such as the shift from petrol to diesel tractors. Thus, the functional variables bypass many of the sins of omission and commission in the measurement of technology.

Fourth, it is evident that one focal point of the systems view of technology is changes in the product characteristics. This is in marked contrast with the neoclassical view, according to which the product characteristics do not change. However, it is in keeping with the objective most frequently stressed in actual R&D activity. Thus, it has been observed that the R&D carried out by 90% of manufacturing firms is directed at the development of new products or the improvement of the old. This finding is confirmed by a number of other surveys indicating that three quarters or more of the results from R&D involved changes in the product characteristics. That is, the systems view appears to be more closely tied to the actual aims of modern-day R&D activity in comparison with other viewpoints.

Fifth, the systems view of technology has a number of important implications for a wide variety of problem areas. As discussed above, it is of particular significance to the problems of appropriate technology in developing countries and the management of R&D. It is further relevant to the multidimensional nature of the diffusion of innovations and long-term economic growth. In summary, the functional view of technology may well be a prerequisite to an adequate understanding of a variety of interrelated problem areas and policy issues.

All in all, the systems conception of technology has a number of advantages over other schemes. Nevertheless, it does suffer from three interrelated limitations. First, curious as it may seem, data on change in the functional characteristics of technologies over the course of time are typically absent. This is not to say that they cannot be compiled; rather, they are not as readily available as, for example, patent statistics.

Second, it is evident that technical change in any given product or process tends to take place in several dimensions. As an obvious example, consider innovations in transportation technology, which have led to a multiplicity of advances such as increased speed, reduced fuel consumption, and increased thrust-to-weight ratio. This raises a very important question: how can the various functional properties of a system be appropriately weighted and combined into a single composite index? At one time this problem seemed to defy solution. Results of more recent research do make some headway in this area. However, it is evident that these methods require considerable amounts of data, which adds to the difficulty noted above. Thus a great deal of further effort is required in this direction.

Third, the systems approach is best suited to the microlevel of analysis. Its application at the macrolevel — for example, to a comparison of the performance of different industries, or sectors, or economies — is much less straightforward. This is not to say that it cannot be fruitfully pursued at an aggregated level of technological activity. Rather, more work is needed in this area. In particular, it seems clear that it may be useful to combine the systems approach with other concepts such as the production function. An example of this combination is the concept of an "engineering production function". In principle, we can conceive of many other ways in which different approaches can be usefully pursued in conjunction with each other. However, while the value of an eclectic approach seems beyond dispute in this case, a great deal of further effort is required to find out just what all the possibilities of synthesis are.

1.2. TYPES AND FORMS OF TECHNOLOGY

The technologies used in manufacturing firms may be classified as follows, taking their features into account:

a) traditional technologies: highly consolidated production systems, characterized by relatively simple operations and slow renovation;

b) advanced technologies: production systems developed mainly after the Second World War, characterized by complex, refined operations and a high speed of renovation;

c) mixed technologies: production systems in which the characteristics typical of advanced technologies are prevalent, but not total, and which also include some characteristics of traditional technologies;

d) intermediate technologies: production systems in which the characteristics of traditional technologies are prevalent, but which also include some characteristics of advanced technologies.

The technological level in production sectors may be distinguished on the basis of various elements: type, speed of renovation, diffusion, influence on the added value of the product, and research, development and licence expenditure.

Of these, the added value is certainly very significant: the advanced and mixed technologies nearly always produce a high added value, traditional technologies tend to give a low added value, and intermediate technologies an average added value.

There is nearly always a heavy increase in the value of raw materials in manufacturing, electronic and aeronautical industries, in secondary chemical and specialized industries (plant protection products, surfactants, dies, pharmaceuticals and others); by contrast, there is generally an average value in inorganic and intermediate chemical industries; while there is a low added value in the food industry, natural textile fibre processing, footwear, and building materials.

The speed of technological renovation is also an element used to distinguish among the various technologies; activities based on traditional and intermediate technologies adjust their production systems in no less than 10 years; mixed technologies in 5 to 10 years; advanced technologies every 1 to 5 years.

Another element characterizing technological levels are the research, development and licensing expenditures; the more advanced the technology in an activity, the higher these costs are, especially relative to the sales of the company.

On this basis a classification has been developed which, though approximate, allows at least a basic distinction between advanced, mixed, intermediate and traditional technology sectors (Leoni, 1989).

The classes of research, development and licensing expenditures are expressed as a percentage of sales: over 4%, from 2 to 4%, from 0.5 to 2%, and less than 0.5%.

The classification is shown in Table 1.1. Branches with traditional technology mainly include the textiles, food, paper, wood and building materials industries; intermediate technologies are used for the basic inorganic chemical industry, the iron metallurgy industry, non-ferrous metals and the car industry; mixed branches include basic organic chemicals and secondary and inter-

TABLE 1.1. Branches with different technologies
Costs for research, development and licensing (% of sales)

Group IV Traditional technology, < 0.5%	Group III Intermediate technology, between 2 and 0.5%	Group II Mixed technology, between 4 and 2%	Group I Advanced technology, > 4%
Textiles, clothing, footwear	Inorganic chemicals	Basic organic chemicals	Aeronautics
Foodstuffs	Iron metallurgy	Secondary chemicals	Instrumental electronics - computers - components
Paper	Non-ferrous metals	Intermediate chemicals	
Wood	Railways		Instrumentation
Building materials	Petroleum	Motor Vehicles	Pharmaceutical
		Appliances	Artificial and synthetic fibres
		Non-electrical machinery	Plastics
		Electrotechnical	Frozen and freeze-dried foods
		Rubber	
		Electrochemicals	

mediate chemicals, petroleum, electrotechnical and rubber industries. Technologically advanced branches include aeronautics, electronics, precision instruments, artificial and synthetic textile fibres, plastics, and frozen foods.

Further classifications of technology are linked to the transfer process.

The form taken by scientific and technological knowledge, thus the subject of technological transfer, is only weakly correlated to the technical-scientific sector to which it belongs, and may be defined in general terms.

An initial classification may be: hardware technology and software technology.

The former is what is transferred as "incorporated" equipment, plants or other products that make innovative industrial production processes possible. Software technology includes instead any possible type of coding and extrinsication of scientific and technological knowledge in abstract form, thus articles and publications, documentation, know-how; the latter may be either coded in general forms or incorporated into the specific experience of people.

This classification may be further specified by linking the content of technological transfer operations to the means in which the transfer itself takes place. We can therefore distinguish between:

- *alienated technology:* or privately-owned technology that is granted in virtue of ownership rights and based on a special agreement. This is made up of confidential information, patented know-how and technical assistance provided on the basis of commercial agreements;
- *socialized technology:* technology and knowledge that is socially available and unrestrictedly accessible. This mainly consists of knowledge generated by public research and made available to the community (public agencies, universities);
- *interiorized technology:* basic knowledge, know-how, experience and ability to resolve technological problems, as possessed by individuals;
- *capitalized technology:* the technology incorporated and "crystallized" in capital goods, intermediate goods and finished goods which may, therefore, be transferred and acquired by purchasing such goods.

1.3. THE SCIENTIFIC APPROACH TO TECHNOLOGICAL DYNAMICS

The current technological evolution is unique in human history for its ability to transform any type of activity and organizational structure. The innovative process thus goes well beyond the technological dimension, to involve socio-economic, psychological, and cultural aspects.

The current situation is complex due to the fact that there are various technological waves that intersect, in addition to those of microelectronics and computers: think of robotics, the new materials and new energies, biotechnologies, new process technologies (such as the laser), the use of the sea and space.

These factors lead us to believe that this moment in history cannot be assimilated with the rising stage of a Kondratiev wave — typical phenomenon of a society born of the industrial revolution — but that it must instead be considered a more profound change, which will lead to increasingly radical changes in today's industrial societies.

The industrial revolution marked the passage from an essentially agricultural society to a prevalently industrial society. There have been various long-term technological waves, occurring with the creation of relatively rigid systems around certain large productions and supporting branches: the steam engine, textiles, steel, electricity, chemistry, petroleum, the automobile. Industrialization, urbanization, transportation, industrial democracy are fundamental aspects of the industrial society.

The societies born of the industrial revolution have had increasing recourse to mass and standardized productions.

In the 1970s — after the first and second oil crises which changed the basic conditions of development — the situation changed profoundly. The mass markets began to be saturated, numerous and increasing cases of productive overcapacity occurred, the rigidity of large-scale economies became evident. In addition, worries and conditions for environmental and safety problems grew. The economy passed through periods of recession and recovery, with inflation, unemployment, imbalances in international trade. The market demands changed towards better quality, personalization, diversification of goods and services, to better respond to specific needs.

The crisis of the 1970s even led some to believe that the possibilities for innovation had dried up. On the contrary, in the 1980s new technologies boomed, with the increased capacity for mutual interaction and fertilization, with the enormous range of options that they offer to problem-solving, with the possibility of rejuvenating sectors considered to be mature (Jelinek, 1993; Martin, 1994).

Perhaps the most salient feature of the new phase of development is the scientific approach to technological development. Technology no longer develops independently of science: it is born from and developed on a scientific foundation, as a form of scientific knowledge in itself.

In the past, the great technological developments came about even before they could be explained in the light of scientific theories. This is the case, for example, of Watt and the steam engine: Carnot's fundamental study of thermodynamics did not arrive until a few decades later. Edison developed the incandescent light bulb long before the solid emission theories were perfected. And Marconi invented the radio with only a superficial knowledge of the scientific works of Maxwell and Hertz.

These three examples, if examined in greater depth and if their history is followed, show that in the past it was the invention and its diffusion on the market that stimulated and gave life to scientific activities.

More recently, things have happened in quite a different way. For example, the control of nuclear fission achieved by Enrico Fermi derives directly from the research carried out by Fermi himself and his school on nuclear physics. The same is true for the development of the transistor, which resulted from years of study of solid-state physics and the nature of imperfections in solids.

Today, many new technologies would be unthinkable if there was not a simultaneous body of work aimed at providing the appropriate scientific solu-

tions. That is why it is very difficult to distinguish the confines between further developments of scientific knowledge and the technologies that take advantage of them.

Man is now increasingly able to "invent" the resources he needs. Uranium, for example, was not an energy resource until nuclear fission reactors were invented. Progress in nuclear fusion technology will also make it possible to free energy from lithium and water. In both cases, technology is the true factor that produces energy, rather than the raw materials used in the process. Silicon, the basic raw material for the micro-electronics industry and thus a vital factor for every country in the world, is considered a resource generator, as it makes computer science possible, for example, and the photovoltaic conversion of solar radiation. Other materials, such as the new ceramics, extra-high-resistant technopolymers, and high-module fibres were invented "from scratch", based on the scientific knowledge of the basic properties and structure of solids.

In this way we tend to overcome the concept of a planet, in the sense of a sphere containing a limited quantity of resources from which these may be taken (until they eventually run out). Today we instead face the problem of developing the new resources that man will need in time, and taking into account a number of factors (including economic competitiveness, technical needs, environmental effects, physical safety and security), by means of adequate research and development.

Scientific technology — like science itself — appears to be an increasingly universal tool, that may be used anywhere, in industrialized countries as well as developing ones. However, since it is not made for rigid solutions, but opens up broad ranges of different options, it allows the choice of the solution most suited to the various economic and cultural contexts, taking into account the traditions, needs, professional skills, and strong points of each country.

We should point out, however, that science also proceeds separately from the special aims of technology, and is thus capable of increasing knowledge independently.

1.4. TECHNOLOGICAL SUBSTITUTABILITY

One of the fundamental moments in studying technologies and industrial productions is related to the concept of "substitutability": that is, a principle of substitution (or competition) exists in specific sectors among various

processes and goods or among factors, to a greater or lesser degree depending on the sector.

This concept is fundamental, since by setting up an economic study from this standpoint, the productive factors may be examined and discussed with a dynamic view.

The various factors combined together make it possible to obtain either identical products using different methods (different production cycles or technical organizations), or different products using different methods and factors, which however satisfy the same type of need.

If we take into account that the possibility of substitution exists (and will continue to increase) among various goods with reference to their use and not only to their characteristics, we can better succeed in changing certain orientations in relation to new needs that differ from current ones.

Substitutability may occur:

a) between identical goods, which are produced using different methods but which use the same raw materials;

b) between different goods, obtained using different production processes, using different raw materials, which have similar characteristics and may therefore be used for the same purpose;

c) between production factors (for example, between capital and labour);

d) within the same factor (raw materials, labour).

An historical example of the first instance, which however is generally valid, is that of soda. From approximately 1820 to 1900, sodium carbonate — one of the first products obtained using industrial criteria — was obtained using the Leblanc method, beginning with sodium chloride, sulphuric acid, coal and calcium carbonate (Ciusa, 1962).

After two processing stages, sodium carbonate was obtained along with other products, such as hydrochloric acid and calcium sulphide, which could not be considered by-products as they had no use or economic value. In addition, some of the raw materials used — sulphuric acid and coal — were extremely costly and thus all of the costs were born by a single product.

Later (in 1872), the Solvay method was developed, whose use was delayed due to the lack of equipment suitable for handling large masses of gas: the method consists of having ammonia and carbon dioxide react in a solution saturated with sodium chloride; this produces sodium bicarbonate and ammonium chloride.

The first is calcined and converted into sodium carbonate and carbon dioxide, while the second is treated with lime and leads to the production of

calcium chloride and ammonia.

The carbon dioxide is mostly recovered and recycled, as is the ammonia.

With the Solvay process, the equipment costs were certainly higher than for the Leblanc process. When the systems were improved and the costly loss of ammonia, which occurred in the original operating periods, virtually eliminated (the Solvay process uses a nearly closed cycle, totally recycling the ammonia and most of the carbon dioxide) the production cost of sodium carbonate quickly became competitive, to the point that the Solvay process completely replaced the Leblanc process in just a few years.

Furthermore, it is worth noting that Solvay sodium carbonate was much purer than the Leblanc.

Currently, in many uses, Solvay soda (sodium carbonate) can be substituted with caustic soda (sodium hydroxide) obtained using electrolytic means. Caustic soda is competitive because it starts from the same raw material — sodium chloride — and has a simpler processing cycle than Solvay, using mercury which, although expensive, is mainly recovered and recycled at the end of the production cycle, which produces two joint products — caustic soda and gaseous chlorine, both with a considerable and similar economic value. Therefore, with the possibility of dividing the shared costs between two products of similar value, the cost of the caustic soda thus obtained is lower than that of Solvay soda, as the sole product of a more complex cycle.

In the end, in productions in which the two different products may be used interchangeably — which can be ascertained in advance — caustic soda is taking over. Except, of course, for the fact that the mercury, though nearly fully recovered, remains in the processing water which is later discharged, and becomes a pollutant.

A similar situation has occurred for sulphuric acid produced using the lead chamber method and the direct catalytic (contact) method.

An example of the second case of substitutability between products is found in the aeronautics industry, which requires materials that are light but resistant to the mechanical stress caused by the speed and the succession of accelerations. In the building of Concorde, aluminium, nickel and magnesium alloys were chosen; titanium alloys will instead be used for the Boeing 2707, though the project is momentarily shelved.

The criterion of substitutability not only occurs among finished products, but may also be characteristic of the production cycle: among raw materials, or between the capital factor and the labour factor.

Thus various types of acids may be used in converting phosphorites or apatites into phosphatic fertilizers; the most commonly used is sulphuric acid, which produces mineral superphosphate with 20% phosphorous pentoxide. Nitric and hydrochloric acid are not economical to use as a substitute for sulphuric acid, while the substitution and use of phosphoric acid may be convenient, as the final fertilizer, although it contains the same active principle, is more concentrated (46% over 20%), leading to great advantages in transportation.

However, the analysis of production functions, and thus production costs, can show which acid gives the lowest cost per unit of phosphorous pentoxide, and thus allow us to establish whether, and to what degree, the various factors included in the production cycle may be substituable among each other or substituted with other factors.

Another example of substitutability among identical raw materials in the same production cycle, but originating from different resources, is found in the products of organic chemical and petrochemical industries.

In order to obtain products — such as plastomers, elastomers, synthetic fibers, dyes and synthetic detergents — the basic components may be obtained equally from either coal or petroleum, except for a few limitations due to the different purity of the respective compounds.

Until now, the decision to use one or the other has been based on economic convenience, in turn a direct consequence of the technical possibility of obtaining them from carbon or petroleum.

In truth, the substitutability is complete for linear hydrocarbons (saturated or unsaturated), but it is not total from a technical standpoint for aromatic cyclic hydrocarbons, as there are differences between the ratios of the amounts of the various aromatic hydrocarbons (benzene, toluene, xylene) obtained from petroleum using common processing methods (10–40–50) and the ratios demanded by the market (65–20–15). By using coal tar, the percentage ratios are instead 80–15–5, respectively. Thus, when beginning with petroleum, toluene and xylene should be transformed into benzene; this is technologically possible, though very costly.

However, the technical possibility of substitution remains, and thus organic chemical and petrochemical industries are in mutual competition.

Substitutability naturally implies a high level of elasticity of substitution; however, some productions might exist that do not offer such possibilities of substitution.

The trend in modern companies is towards production systems that allow increasing possibilities of substitution among various production factors. In-

deed, if the production is rigid and the production factors cannot be changed or replaced, should company or market reasons require it, the company cannot adapt quickly or even completely reorganize the production cycle, with foreseeable economic consequences. If instead the company has the possibility of rapidly adapting its production to needs that arise at a certain moment, it is clear that it can enjoy the advantages of this. That is why, if entrepreneurs are capable of facing this type of problem, taking into account the technical-production aspects in particular, they can make medium- and long-term forecasts more easily and accurately, and thus make the most appropriate decisions.

The degree of relative change in the proportions of factors that make up the lowest cost combination, in response to the relative change in the respective prices, is known as the "elasticity of substitution coefficient".

It should be pointed out that a change in the production combination may take place by shifts along the same production function, or by transposing it.

In simpler terms, it can be said that the production combination may change if the company has the chance to use the productive capacity of the system more intensely, to respond to an increase in demand for the product (shift along the same production function); but the combination may change for another reason as well. For example, if the business changes technology for a long-term transformation, and renovates or expands its plant (passage to a different production function).

The measurement of elasticity of substitution is valid if applied to short-term changes, thus to shifts along the same production function.

1.5. THE OPERATIVE PROPERTIES OF TECHNOLOGIES

In order to obtain objective elements for assessing the "quality" of the technology currently employed (so as to be able to pin-point not only its strong points but also its weak ones), we propose a "technological index" which can be obtained by considering the most significant parameters; that is, those most capable of expressing, concisely, the salient operative properties of technologies.

The most significant parameters may well be numerous. They must, obviously, be able to be measured in a reproducible way. Above all, determining the reliability of the process in all its phases is an indispensable step.

Process reliability. This represents the overall probability of defects occurring in the man-machine system; i.e., those which might lead to breakdowns, slowdowns, and operative imprecision.

Process reliability is defined by means of fault tree analysis (FTA) which, in a process consisting of various stages (stations, shops), reflects the probability of negative events occurring during these same stages. If the probable disadvantages are mutually independent, they are added; if dependent, they are multiplied (Henley and Kumamoto, 1984; Himmelblau, 1978).

The single probabilities are reformulated on the basis of statistical calculations that utilize values of specifications of each plant component. These can be derived from a detailed project-in-process. Such elaboration is tested, proved and applied by the plant technicians. The lower the probability of drawbacks, the higher the process reliability, which usually varies from 10^{-1} to 10^{-6}. This property is widely utilized in industry.

Process capability. A second parameter concerns with conformity to product specifications, or process capability. This represents the degree to which the properties can be reproduced, and may refer to a single property/performance factor or to a group of these, taken as a whole.

The process capability index is obtained by measuring the dispersion of a single property or group of them. The difference between the upper specified limit and the lower specified limit must be ascertained and then expressed relative to 6σ, where σ is the normal standard deviation.

If the product is complex, then one needs to refer to different specifications. These can also be synthesized into a global performance index (GPI).

The formula for measuring the conformity rate of a given product is

$$Conformity = \frac{upper\ specified\ limit\ -\ lower\ specified\ limit}{6\sigma}$$

A process capability index of 1.0 is the minimum requirement. The higher the value, the greater the conformity of the product to specifications. The index, however, rarely exceeds a value ranging from 4 to 5.

Real machine capacity. The third parameter concerns quantitative aspects and, consequently, process effectiveness. This represents a measure of the actual production capacity of machinery installed with a specific technology, considering loss factors (due to stoppages, reduced production rate, defects) (Bedworth and Bailey, 1982).

TABLE 1.2. Evaluation of principal loss factors

Principal loss factor	Cause of loss	Output index
Stoppages	Unforeseen breakdowns Set-up Adjustments	$E_1 = \dfrac{T - T_f}{T}$
Reduction in speed	Idling Brief stoppages Reduction in speed	$E_2 = \dfrac{T_c \times Q}{T_e}$
Defects	Rejection during process Rejection at starting	$E_3 = \dfrac{Q - Q_s}{Q}$

Principal loss factors can be listed as follows:
loss due to stoppages
loss due to reduction in work speed
loss due to defects.

Each loss may be evaluated as shown in Table 1.2, where T = machine running time; T_f = machine stopped time; T_c = theoretical lead time; Q = quantity processed; T_e = actual working time = $T - T_f$; Q_s = quantity of scrap (defective items rejected).

The quantity of scrap material is expressed in terms of defective units rejected in unit time, relative to their required specifications, their limits and their tolerance.

Thus the index of real capacity can, in synthesis, be expressed as

$$E = \frac{T_c \times (Q - Q_s)}{T} = E_1 \times E_2 \times E_3$$

The higher the result, the more favorable it is. It commonly lies between 70% and 95%. Also this property is widely utilized in industry.

Flexibility. The fourth parameter, which completes the preceding one, expresses the degree of process flexibility. This represents the set-up time, i.e. the time necessary for preparing equipment for the manufacture of diverse products, relative to the lead time, or total time needed to produce the same items. It is measured thus (Raouf and Ahmad, 1985; Hartley, 1984; Ranky, 1993):

$$\text{Index (set-up)} = \frac{\sum_{1}^{n}{}_{i}(N_i \cdot t_{si})}{\sum_{1}^{n}{}_{i}(N_i \cdot t_{si}) + \sum_{1}^{n}{}_{i}(R_i \cdot t_{mi})}$$

where N_i = total number of set-ups for item i, obtained from the equation

$$N_i = \frac{R_i}{q_i} \quad \frac{(\textit{requirements of item } i)}{(\textit{lot size of item } i)}$$

t_{si} = set-up time of item i; t_{mi} = unit manufacturing time of item i.

The shorter the set-up time — the number of products being equal — the greater the flexibility, which usually ranges from 10 to 80–90.

A synthetic "process quality" index can also be calculated by means of a simple method using nomograms, and which makes it possible to arrive at two intermediate sub-indices. The procedure to be followed is shown in Table 1.3 and Figure 1.1, which also provide three examples (Barbiroli, 1989a).

The calculation of indices that become more and more general to reach the expression of a global evaluation index makes use of a hierarchical structure that may be defined as a "binary tree". In other words, the index at each level is related to a "predecessor" (the index at the immediately higher level) and two "successors" (the indices at the lower level). The global index, the highest index, and the basic index at the lowest level are obviously exceptions to this. The binary structure is not in fact restrictive because every tree of greater complexity can be described in binary terms through the application of an appropriate expansion of levels. In any case, the consideration of trees of a ternary or quaternary structure presents no difficulty, should this be requested for an interpretation of the intermediary indices.

Each node of the tree is generally represented by four attributes: (a) the current value, (b) the minimum forecast value, (c) the maximum forecast value, and (d) the weighting for the evaluation of the subsequent index. Starting from the basic indices (level zero) and passing through each successive level until we obtain the final index, each index of a higher level will be given by a weighted average of its successors, subject to normalization on an absolute scale. At level k we thus obtain

TABLE 1.3. Parameters utilized for assessing the operative properties of technologies

Parameters	Sub-indices	Description	Variation range	Examples A	Examples B	Examples C
Process reliability	Process quality	Probability of faults in a year	10^{-1}-10^{-6}	10^{-3}	10^{-5}	10^{-6}
Process capability (uniformity)	Process quality	$\frac{\text{upper limit} - \text{lower limit}}{6\sigma}$ Measured for one or more products specifications	1-5	1,6	2,5	2,0
Real potential	Process efficiency	$E = \frac{T_c \cdot (Q - Q_s)}{T} = \%$ Real obtainable production	0-100	84	89	77
Flexibility	Process efficiency	$\frac{\sum_1^n (N_i \cdot t_{si})}{\sum_1^n (N_i \cdot t_{si}) + \sum_1^n (R_i \cdot t_{mi})} = \%$ Ratio of set-up time to total producing time	0-100	40	60	20
Global index				64.5	66.6	70.5

$$x_j^{(k)} = \left[x_{j,\min}^{(k)} - \sum_{i \in S(j,k)} \lambda_i^{(k-1)} R_{i,k-1}^{j,k} \; x_{i,\min}^{(k-1)} \right] \tag{1}$$

$$+ \sum_{i \in S(j,k)} \lambda_i^{(k-1)} R_{i,k-1}^{j,k} \; x_i^{(k-1)}$$

with the following meanings for each symbol: $x_j^{(k)}$ is the value of the index j of level k, $x_{j,min}^{(k)}$ is the minimum forecast value of index j at level k, $\lambda_i^{(k-1)}$ is the weight to be given variable i of level k-1 in defining the variable of this subsequent level, $S\ (j,k)$ is the set of indices of the "successors" of variable j of level k, and

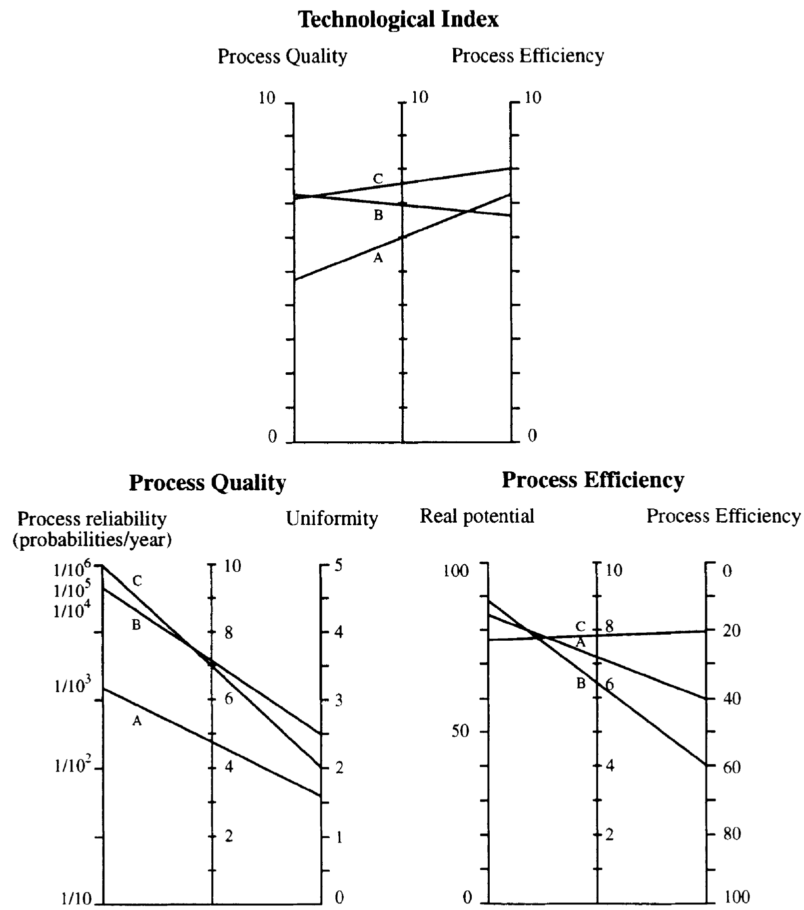

Figure 1.1. Nomograms used to obtain the process global quality index

$$R^{j,k}_{i,k-1} = \frac{x^{(k)}_{j,\max} - x^{(k)}_{j,\min}}{x^{(k-1)}_{i,\max} - x^{(k-1)}_{i,\min}}$$

is the scale ratio between variables j of level k, and i of level k -*1*.

It should be noted that the weights $\lambda_i^{(k-1)}$ must satisfy the relation of normalization:

$$\sum_{i \in S(j,k)} \lambda_i^{(k-1)} = 1$$

As can be seen, the calculation of the global advantage index can be made recursively, starting from the global index $x_1^{(k,max)}$ itself. However, when the tree structure is "regular" (in the sense that each node has the same number of successors) a non-recursive calculation (starting form the base indices of level zero) permits the use of simpler programming techniques and languages.

1.6. THE DISSIPATIVE PROPERTIES OF TECHNOLOGIES: AN EVOLUTIONARY VIEW

All production processess and technologies involve the transformation of energy and materials, transformations which are subject to specific natural laws. Thermodynamic principles govern the flows of energy and matter in nature, and an understanding of them is therefore essential to see the connections of economic systems to the ecosystems. Such un understanding is also essential to any technological approach (such as that of re-producing, industrial metabolism, clean production) which seeks to address the environmental problems arising from the economic system of production and consumption.

Thermodynamics was born with the industrial revolution. It was developed at the same time as, and as a direct result of, the advent of steam power in Britain during the early 19th century. Concerned with understanding the efficiency of the newly developed heat engines to deliver useful work, it is a theory intrinsically related both to industrial processes and — as Georgescu-Roegen (1971) has pointed out — to the economy.

The sphere of reference of thermodynamics may be extended to the movement of energy generally; and as a result of the interrelationships (both nonrelativistic and relativistic) of matter flows and energy, thermodynamics is applicable to all material and energy flows.

The general picture presented by the thermodynamics of any system involving energy and material transformations may be summarized in the following way. Energy and material transformations tend to occur in such a way as to reduce the available energy in the system and to increase the dissipation of materials throughout that system. In an isolated system, this tendency will lead to thermodynamic equilibrium in which no further activity is possible. In a system open to the interchange of energy or materials with its environment, the tendency of the system to move towards thermodynamic equilibrium can only be offset by importing high quality energy from outside the system and exporting entropy from the system. In ecological systems this ability to export entropy is crucial to survival.

The first and the second laws of thermodynamics are of importance to the biophysical nature of the economic system. The first is the conservation law and informs us that, whatever the form of energy before and after transformation, the total quantity of energy is conserved.

The second law of thermodynamics concerns the "quality" or "availability" of energy and the way this is changed during the process of transforma-

tion. It states that heat will not pass spontaneously from a cooler to a warmer body. An equivalent formulation is that — despite the conservation law — it is impossible to transform heat energy (at a uniform temperature) into an equivalent amount of work. The second law therefore imposes qualitative constraints on transformations not revealed by the first law. The picture which emerges is one in which energy states are continually degraded (from high quality to low quality or equivalently from high availability to low availability) through the process of transformation. Although the same "quantity" of energy exists after the transformation as before it, a certain proportion of the available energy has been dissipated through the transformation process and is no longer available to perform work in subsequent transformations. In an isolated system, this means that the system moves closer and closer to a state of thermodynamic equlibrium in which no energy is available to perform any work, and all activity must cease. Conversely, the maintenance of a system away from this equilibrium position is reliant on a continuing input of high-quality (available) energy.

Several important concepts extend this energetic discussion to materials flows. One of these concepts is that of "entropy". The second law states that in the course of a thermodynamic transformation, at least some of the system energy moves from the available to the unavailable state. Entropy can be construed as a measure of the unavailable energy of the system. Consequently, the second law states that thermodynamic transformation are characterized by the production of entropy. If the system is isolated then we deduce that transformations consecutively lead to higher and higher levels of entropy in the system. In an open system, entropy within the system may be nonincreasing — despite the production of entropy during thermodynamic transformation — because the system is able to export entropy and to import available energy. In these circumstances, the increase or decrease of entropy in the system depends on the relative rates of production and export of entropy.

Entropy is closely related to the concept of the chemical thermodynamic potential. This concept extends the idea of potential energy (i.e., stored energy) to the domain of the energy stored in chemical bonds. The thermodynamic potential of a chemical can be thought of as a measure of the free (available) energy associated with that particular substance and therefore as a measure of ability of that chemical to perform work. Those substances which have a high chemical thermodynamic potential have high levels of available energy and are therefore able to perform work. Such substances

are therefore characterized by low entropy. Low thermodynamic potential, conversely, is associated with low available energy and high entropy.

The relevance of entropy for matter is most clearly illustrated by Boltzmann's historic statistical interpretation, which associates entropy with the degree of "disorder" or dissipation of materials in the system. The increase in entropy associated with the second law indicates that thermodynamic transformations are characterized by increased dissipation of matter through the system. For a closed system, this tendency to dissipation will lead to a tendency for mixing of the material basis of the system. Heuristic support for the "order" and "disorder" interpretation of entropy is provided by the observation that materials with high thermodynamic potential are generally those which are purer and more concentrated, whereas those with lower thermodynamic potential are less pure and more dissipated.

The second law characterizes economic processes as essentially dissipative of both energy and materials. Economic resources pass through the system and become wastes, but the second law does not admit the reversibility of the classical viewpoint, highlighting instead the inherently dissipative nature of the economic process. Without reference to this entropic throughput it is virtually impossible to relate the economy to the environment.

In order to completely analyze the underlying reasons of the current context between economic systems and the ecological system, one must consider the principles that govern the evolution and metabolism of each (Ayres et al., 1989; Ayres, 1993).

The interactions between economy and ecosphere can be better understood by considering two reasons: the first, since the relative success of ecosystems in self-organization from the perspective of long-term sustainability provides specific indications as to how to orient economic systems towards the same objective; the second, equally important, since the behaviour of ecological systems under the influence of thermodynamic factors is crucial in regulating the impact of the flows of energy and material in the economic system.

The thermodynamic analysis of ecological systems has been examined to some depth after the original observations by Lotka (1925), according to whom "natural selection takes place in such a way as to increase the circulation rate of matter through the system, and to increase the total flow of energy the more unused residue of available matter and energy is present".

This principle was then considered to be the principle of "maximum production of binding entropy" (O'Connor, 1991) due to the entropic nature of the processes of converting energy and matter.

Thus entropy sets strong limitations to transformations, and must be associated with the idea of "disorder" and "dissipation" of materials and energy in the system.

The thermodynamic view of ecosystems, which has been developed in recent decades (Georgescu-Roegen, 1971; Finn, 1986; Coveney and Highfield, 1991) considers that the self-organization and creation of new and complex structures takes place as the result of "dissipative structures" (Prigogine and Stengers, 1984), which convert high-quality input into energy and reverse the production of entropy associated to the second law of thermodynamics. This second task is essential to the maintenance and survival of both individuals and the global ecosystem, and thus has a strong weight on the system in terms of the requirement of maintenance energy. In other words, each living organism requires a constant amount of high-quality energy in order to live, and additional energy is needed to grow, produce and organize what is needed by the community (Jackson, Costanza, Overcash and Reeds, 1993).

A key factor in this process is the availability of high-quality solar energy (as for chlorophyll photosynthesis, which in thermodynamic terms is the most important production process on earth, to the point that it keeps the ecosphere a system that continually differentiates itself).

Photosynthesis itself is subject to the laws of thermodynamics, in the sense that there are limits to the efficiency of converting incoming solar radiation; it is calculated that the rate of solar energy conversion during cycles of photosynthesis is around 1-2%.

Therefore, considering the earth as a system, this photosynthetic energy powers the ecosphere and allows it to proceed towards increasingly more organized structures.

This energy is specifically required to counter the dissipative tendency of the flow of materials, and the global ecosystem has developed a complex network of interactive material cycles (biogeochemical) to perform this task. Since the useful energy is carried in material form, survival depends on the existence of cycles that use flows of negative entropy.

These transformations should not be considered anti-entropic simply because they locally allow some materials to switch from high to low entropy; indeed, these processes — viewed from a global standpoint — dissipate both matter and energy.

Dissipated matter is recycled by biogeochemical cycles guided by the sun, which in turn are equally dissipative; thus the accumulation of high entropy, low-grade heat, is transferred to space, and the energy balance is maintained

by high-energy solar rays. Therefore, these cycles not only maintain but also regulate development and reproduction in ecosystems. They generate a "cybernetic feedback" mechanism which helps individual systems to be stable and resist outside pressures (Brewer, 1979).

The process of "self-organization" in ecological systems is thus the result of co-evolution of the complex, interdependent relations that link the components of the ecosphere; and the structural integrity of these relations is essential not only in order for the system to function, but also for the production and maintenance of individual components.

However, there have been explanations of the phenomena that give life to the ecosphere not in an entropic interpretation, based on causality principles, but in a so-called syntropic vision based on the finality principles, as indicated in the unitary theory of Fantappiè (Fantappiè, 1944-1993), corrected by Arcidiacono (1991).

According to this theory — which has been widely discussed and criticized — all phenomena that make up the ecosystem, and thus life, are simultaneously governed by syntropic and entropic principles, which act not by "overlapping" but by "fusion".

It is obvious that one or the other prevails at times; when entropic phenomena prevail, there is a passage from more complex states to more simple states; when syntropic phenomena prevail, the opposite occurs, with high differentiation. It is also possible to have a balance between entropic and syntropic phenomena.

Now, one important aspect must be specified about biological systems which, as we shall discuss, relates to economic systems: from a thermodynamic standpoint, biological systems are characterized by their "ability to evolve spontaneously towards more orderly structures", using the phenomena of energy degradation with which they are associated.

It has been observed that the passage from thermodynamic systems to biological systems is quite similar to what occurs in passing from mechanical systems to thermodynamic systems (Fabrizio, 1987 and 1994).

Biological systems are "open", thus they exchange matter and energy with the environment, and therefore they do not completely follow the laws of thermodynamics. Instead, open thermodynamic systems — such as petrol engines — follow the second principle, which requires the inclusion of a generalized principle of dissipation. For a macroscopic description of biological systems, a new measurement must be introduced, just like temperature, which characterizes the properties of thermodynamic systems in rela-

tion to mechanical systems. Fabrizio proposes that the degree of merit of biological systems be measured with a factor called "self-organization".

Thus, as the first principle ensures the conservation of energy by introducing heat, it may be considered that in the degradation processes of high-quality energy an action is produced capable of producing order to balance the degradation of energy.

For example, in photosynthesis plants absorb energy from solar rays and nutritional substances from the soil and convert them into biological energy (biomass), thus a "vital" action takes place, at the expense of the flow of negative entropy which follows the dissipation of the electromagnetic energy present in sun rays.

Biological processes therefore slow down the degradation of energy resources, taking good advantage of dissipative processes, as found by Prigogine (1962 and 1987). It follows that life is not energy, strictly speaking, but rather a process in which energy and matter are raised to a higher-quality form.

The factor known as "self-organization" should therefore be a measurement of the system's ability to generate order, or in other words the syntropy present in biological systems.

If we now direct our attention to the economic system, we observe two contradictory characters. The first is that, in thermodynamic terms, an economic system is quite similar to an ecosystem, in the sense that it exchanges energy and material with those that border it; the second, which conflicts with the first, is that these thermodynamic principles do not provide a similar regulatory function of the actual behaviour of the economic system. In particular, the second law of thermodynamics characterizes economic processes as highly dissipative of energy and materials: resources pass through the economic system and become waste, in different forms (Georgescu-Roegen, 1971, 1975, 1977; Hall, Cleveland and Kaufman, 1986; Kümmel, 1989). In other words, the conversions of energy and material take place in such a way as to reduce the energy available in the system and increase the dissipation of materials in every point of that system.

In an isolated system, this tendency may lead in the end to a thermodynamic balance in which no other activity is possible (Faber et al., 1996).

In a system open to the exchange of energy and materials with the environment, the system's tendency to move towards a thermodynamic balance may only by compensated by importing high-quality energy from outside the system, and exporting entropy from the system (O'Connor, 1991). We

must remember that, in ecological systems, this ability to export entropy is crucial to survival (Maturana and Varela, 1988).

The activities within the economic system are not determined by our ability to capture and convert solar energy, but go well beyond the limitations imposed by the chlorophyll cycle. The economy, just like the ecosystem, acts as a dissipative structure, converting low-entropy energy and materials into high-entropy energy and materials. However, in order to feed this cycle, the economy also needs to dissipate high-quality energy, because the Second Law must be verified on a global basis. The difference between economy and ecosystem lies in the entity of the phenomena; this means that the ecosystem has a sustainability that derives from its ability to export entropy, while instead the economic system is incapable of regulating its own entropy, with the consequent risks of altering the ecosystem. Among other things, the introduction of additional processes to reduce or eliminate the pollution produced in an open economic system inevitably involves the use of energy and materials, which in turn are dissipative.

What we have described unmistakably shows that an open economic system is dissipative, even if rational criteria are introduced into the processes and structures that utilise resources.

The sustainability of development is instead linked to very different criteria in converting resources and managing products/services, which should be clarified together with the necessary conditions in order to achieve them.

Economic development before 1980 was characterized by the tendency to produce goods with quality and economic features that induced rapid replacement after use, even if they had not completed their technical and economic life-span.

This is especially true for durable goods such as automobiles and all means of transportation, household appliances, even clothing and other similar goods; indeed, the average life of these products has been gradually reduced over time in all industrialized countries, thus as their global demand increased, the direct, indirect and induced production processes have been accelerated and intensified, thus further increasing the energy and materials used and later dissipated.

Taken for granted today that the continued and accelerated use of non-renewable natural resources — especially liquid, solid and gaseous fossil fuels, but also minerals — and renewable resources — especially wood and cellulose, but also vegetable and animal foodstuffs — causes a further, irreversible impoverishment if not exhaustion of the original supply of re-

sources, the basic idea of a sustainable economic system is a use of the resources that does not definitively and irreversibly compromise natural balances, which in any case have already been strongly altered as a consequence of the criteria used for previous economic development. To achieve this objective, the entire international community — especially industrialized countries — must direct every effort towards achieving an actual, generalized "industrial metabolism", which harmoniously integrates into the "natural metabolism" of biogeochemical cycles. This concept has been recently introduced (Ayres et al., 1989; Ayres, 1993).

It should be specified that the term "industrial metabolism" refers to "a set of productive and economic activities that create functional goods, which are inserted in a closed cycle for their entire life-span so as to avoid dissipation"; in order to be fully realized everywhere, this requires first of all a new, general cultural revolution by manufacturers and consumers, which in turn becomes a concrete change in economic choices and behaviours in the direction of sustainable development indicated above.

1.7. TECHNOLOGY AND SCALE EFFECTS

The adoption of a technology may depend on a certain minimum efficient size below which (or a maximum size above which) its use may not be optimum; this means that the introduction of special-purpose equipment becomes feasible only beyond a certain scale. There are many examples, all over the world, of inventions implemented in industry only several years after their finding only because the size of the companies was too small to permit a fast return of the corresponding investments.

A fundamental point in this area is that, whereas the adoption of a new technology becomes flesible only after a certain scale, the scale itself may be a barrier to a technological change, since it requires many adaptations in the existing organization of a plant.

In other words, the features of a technology and of the derived equipment affect the scale, and the scale in turn affects the technological change.

To a certain extent, then, the relationship between a technology and the scale of its operations may well be of a mutually causal nature (Rosegger, 1980 and 1986). We can reasonably assume that technology is more susceptible to the influence of scale than scale is to the influence of technology. As a matter of fact, there are two important reasons for this. First, technology is

only one among a host of factors underlying the observed variations in scale. In general, determinants of the scale tend to be many and the effect of each relatively small.

The second reason is related to the first. The time constants of technological change and scale change differ vastly form each other in their respective magnitude. One key characteristic of the size distribution is that it cannot change rapidly.

The effects of scale may take place at various levels, including:

- the global production of each product over time;
- the products life-span;
- the productivity level of each product per unit of time;
- the standardization degree of the products;
- the production capacities per unit of plant, equipment and production lines;
- the total capacity of a single plant;
- the overall size of a complex of plants in a specific area;
- the degree of vertical integration of a plant;
- the amount of a product sold to each customer;
- the geographical concentration of customers;
- the size of deliveries to each customer.

The product mix plays an extremely important role in achieving positive effects of scale, and the optimal combination of the various possible products may allow — or impede — maximizing the economic result. In the end, the choice of the product mix and production scale for each is an essential element of business management economics.

It should also be clarified that large plants are not a dilated version of small plants, but require different techniques, different methods of organization and different product mixes.

It is also necessary to evaluate whether large multiple-company industries achieve economies of scale different from those that occur at the single plant level. This is an important aspect, especially in determining strategies, in the sense of gradually building increasingly large individual companies, or to divide large companies into small or medium-sized units.

1.8. TECHNOLOGY/EMPLOYMENT RATIO

One of the most important aspects in facing the complex manifestations of technology is the level of investment required in each production sector, in relation to the labour factor.

This ratio differs widely from field to field. In order to provide a quantitative orientation, a specific study was carried out in 55 production sectors, with reference to the years 1976 and 1994, to measure the most recent changes (original figures). The results are summarized in Table 1.4, and are orientative.

From this study, it has emerged that the level of investment per employee currently ranges from \$ 8,000 for the clothing industry to \$ 600,000 for the petroleum industry.

These values make it possible to evaluate the opportunity of satisfying the various needs in the reference areas of a development plan: where available labour exists, with all other conditions being equal, it will be most advisable to formulate policies that tend towards setting up activities with low investments per employee, thus with a high labour density, and vice-versa.

1.9. THE APPROPRIATENESS OF TECHNOLOGIES

The debate on the appropriateness of technologies, which has developed even outside the scientific community, has undoubtedly achieved a very important and positive result, especially in view of future hoped-for changes in the models of economic and social development: to call the attention of the scientific, industrial and political world to the fact that the choice of a technology in a productive process or in organizing industrial and social life is not a neutral process, but is logically determined on the basis of universally accepted criteria and objectives. Even recent experience in industrializing emerging countries and the backward regions of industrialized countries, such as southern Italy, clearly shows that the technologies used in industrial investments were unable — either by nature or due to the way they were translated into organizational and management facts — to adequately respond to the real needs of the regions and their populations. The rationality of such technological choices was substantially determined on the basis of criteria and objectives such as minimizing production costs or maximizing performance, objectives which are in a

TABLE 1.4. Branches of productive activity, in decreasing order of labour intensity

Productive activities	Fixed investments per employee (x 1000 dollars)	
	1976	1994
Clothing	4	8
Footwear	5	10
Clocks	6	12
Paper mills	6	12
Preserved foods	6	12
Ship Building	8	16
Electronic components	8	16
Lamps	8	16
Foundry (2nd casting)	9	18
Leather and skins	9	18
Tobacco	9	18
Computers	9	18
Other textiles	9	18
Food oil industry	9	18
Textile machinery	9	18
Metal working	9	18
Ball bearings	9	18
Non-electronic instruments	9	18
Electronics	10	20
Radio and TV	10	20
Non-metallic minerals (ceramics)	10	20
Polygraphics	10	20
Wool	10	20
Cotton	11	22
Wood and furniture	11	22
Frozen foods	11	22
Agricultural machinery	13	26
Aeronautics	13	26
Railway industry	13	26
Dairy industry	13	26
Wood processing	14	28
Ice cream industry	14	28
Machine tools	18	36
Photo-Cine-Musical instruments	18	36
Rubber	18	36
Alcoholic beverages (beer)	20	40
Milling	38	75
Sugar	44	85
Paper	70	140
Cement	100	200
Aluminium, Copper	110	220
Primary chemicals	130	260
Iron metallurgy	180	350
Petroleum refining	310	600

certain sense extraneous to the regions affected by the industrial investments.

The very acknowledgement of this fact and contrast between the economic and social development needs of a region in which a productive technology is installed, and the need for a rational economy and organization of the external macrosystem, especially the large company, has led to the development of the concept of appropriateness of technologies.

In some cases this concept has been loaded with somewhat "miracle-worker" meanings, which have made it difficult to scientifically develop the notion of appropriateness: according to these positions, the appropriate technology is basically one that solves the major problems of man and society in relation to a set of goals typical, in many instances, of an advanced or post-industrial society. These positions tend somewhat to obscure the debate on the role and appropriateness of the technology, as they attribute the technology with responsibilities and meanings that it does not have, since they confuse the instrumental role of the technology with the aims for which it may be and is used. Technology is indeed substantially a tool for achieving certain goals, in terms of the relationship between the individual, society and the environment. The equation "tool = goal" is not correct, as it prevents us from clearly identifying inadequacies and errors, and from making the necessary changes.

This attitude rests firmly on a negative experience with destructive and pollutant effects which a certain inappropriate use of technology has had on the environment and on individual and social existence.

However, the equation "tool = goal" that supports this attitude is the result of a more or less extensive and deep rejection of technology as a negative and destructive element, and stems from an unclear idea of vaguely bucolic forms of life and lifestyles in which nature must replace the artifice introduced by technology and technological progress.

After this attempt to negatively clarify the meaning of appropriateness of technology, the problem of redefining it appears, in both technical and — especially — operational and application terms.

Beyond the specific models adopted in many studies, it is in any case the adoption of a general model of society, as an open system in the social-technical sense, which correlates on the one hand cultural factors such as ideas, values, norms and thus social and individual ideologies and goals, and on the other the material factors such as physical resources and technologies.

The interaction of these classes of factors, together with the influence of external social systems, such as for example importing technologies developed in other countries, determines the social organization of individual relationships, their production methods, institutions and forms of government, etc., and thus the evolution of the social system itself over time.

Within this context, it is possible to give an operative definition of appropriate technology, in general terms, as the one which — by the effect of its structure and the relationships it establishes with the other sub-systems (including culture, ideologies, social organization, etc.) — determines processes which support themselves and tend towards the growth of the activity of the system, its independence and, in the end, its capacity for survival and development, whatever the origin of the technology, whether within or outside the social system (Barbiroli, ed., 1980; Skwert, 1985).

This definition of appropriate technology has some important consequences.

First of all, the impossibility of proposing types and parameters with an absolute value and meaning, for every environmental condition and every social system. On the contrary, the appropriateness of a technology should be evaluated in relation to the resources and structural characteristics of the social system in which it is inserted or in which it is developed. This process of evaluation must necessarily be based on a realistic model of the social system which explicates the multiple and two-way interrelations among the various classes of factors (cultural, economic, environmental, etc.) with respect to which the probable effects of the introduction of a new technology must be determined.

This type of global analysis is rather difficult to carry out, given the complexity of the social phenomena involved and the larger number of interactions to consider, and thus the number of possible alternatives. To reduce the complexity of the analysis, an iterative process is often used, in which at each stage an open-ring type analysis of the social system is carried out, with one-way relationships among the variables, and assuming certain hypotheses regarding the values and dynamics of certain variables.

In particular, at an early stage the possibilities offered by science and technology are analyzed; in the next stage, the economic and sociological impact of the new technologies is evaluated; in the final stage, political considerations allow the choice to be oriented among the technological options.

The iterative process concludes when sufficient conditions of congruence are achieved among the variables, in particular between technology and social and individual objectives and ideologies.

Another consequence of this approach to the appropriateness of technologies is a critical revision of the relationship between industrialization and development of emerging countries. In many of these, the choice of rapid industrialization processes as a model for socio-economic development has led to widespread phenomena of socio-economic fragmentation, such as the creation of urban ghettos, the separation of the nuclear family, the loss of promotion by traditional activities, agriculture and crafts. This does not mean, however, that industrialization in itself is the antithesis of the development objectives of poor countries. On the contrary, the possibility of certain structural discontinuities between industrial technologies and the socio-economic organization of the social systems of emerging countries should be explicitly acknowledged. What is important, at this point, is to identify in advance the possible points of conflict and plan appropriate interventions, and not only at the level of the intrinsic structure of the technology, but also the interrelations between the technology and the surrounding environment.

From what we have discussed, it is apparent that rigid, absolute definitions of the technologies appropriate to an ideal development model are unthinkable. What is instead possible, and necessary, is to begin with the structural data of the crisis in progress and, from the results of debates on the impact of the technology and the conditions of the countries we call "late-developing", attempt to analytically identify the elements characterizing the technology appropriate for that point in time, valid for a country such as Italy.

The use of the term "appropriate technology" should be clarified, also taking into account the concepts of *soft technology* and *low-cost technology* introduced in the literature. The idea of soft technologies emphasizes the role played by software, and the adaptation of technological research to the need to safeguard, or return to, an ecological balance between production activities on the one hand, and the territory, natural environment and social-cultural values on the other.

As far as low-cost technology is concerned, it resembles the idea of intermediate technology, thus a technology that is not too complex nor jet primitive, and is suited to Third World countries. According to a certain concept of the term, not shared by all, it may be referred both to the costs of the investment (in absolute terms or with respect to the number of jobs created), or to production costs. The suggestion is for small-scale plants with low-cost instrumental goods with a low capital intensity, thus potentially capable of creating high occupation. Appropriate technology cannot

be identified with either of these definitions, but it does include various important elements. Technological appropriateness is a parameter that may be used in reference not only to technology, but also agriculture, transportation and services, in both economic development and economic backwardness.

The hypothesis of appropriate technologies makes sense only within a decentralized development model, which highlights the human and natural resources in a given territory in an integrated fashion.

While we are aware of the limits of a purely standardized approach, and of the compatibility problems of the various features of appropriate technology in individual technological applications, the following elements are considered to be essential:

a) Intensity and type of labour.
b) Rational use of natural (local) resources.
c) Decentralization, in all forms.
d) Creation of a real and increasing pluralism (including the technical one).

a) Intensity and type of labour. The appropriate technologies are characterized first of all by a relatively low ratio between fixed assets and employed labour. Thus the total initial investment required in order to begin such industrial initiatives will tend to be lower, although lower fixed capital input may lead to higher investments in research.

It should also be emphasized that, given the innovative and technology-intensive nature of these solutions, the share of the labour force with medium and high-level qualifications will presumably be much higher than in traditional production structures.

This first basic feature makes appropriate technologies especially suitable for inclusion in a global, long-term strategy towards full employment.

b) Rational use of natural (local) resources. This feature shall lead both to the traditional resources savings and the enhancement of the local ones, which very often have been neglected. This new direction of industrial activities entails the adoption of new criteria in selecting the type of production technologies and their location.

c) Decentralization. The divisibility of fixed capital and production technology in small plants scattered in terms of space is the condition for taking utmost advantage and making non-destructive use of local resources, both human and natural.

Decentralization permits a less-intense, timely use of the territory, making it possible to use interlying areas less sought-after from an agricultural and environmental standpoint, for housing and industrial settlements; on the other hand, it prevents the abandonment and consequent degradation — both social and physical-geological — of marginal areas such as mountains. At the same time, dispersion prevents environmental pollution from reaching critical levels, as occurs in large concentrations.

Furthermore, only a decentralized structure based on small-medium units can allow a rational use of natural resources (diffused sources of energy, especially solar, materials, etc.) that exist locally on a small scale. Similarly, the heritage — often significant — of productive and cultural traditions and experience proper to special minor urban environments and particular areas can be recovered and taken advantage of.

Another essential aspect of decentralization is given by the possibility of a more democratic organization, participating in decision-making and management processes.

d) Technological pluralism. To conceive of appropriate technologies as a simple alternative to existing technologies in all sectors would be unjustified, as well as unrealistic.

On the contrary, the primary aim to pursue should be an appropriate set of technologies, starting with an approach that may be called *technological pluralism*, to emphasize that the appropriate technologies complement other, large-scale and capital-intensive technologies.

A strategy of technological pluralism may be developed both at the intrasectorial and intersectorial levels; that is, identifying various possible technological solutions within the same sector, and on the other hand defining the productive areas most suited to receive the introduction of appropriate technologies in particular territorial contexts. Even within a sector, such as the iron metallurgy sector, traditionally characterized by rigidly capital-intensive technologies, there is room for various technological solutions: alongside cycles with a high capital density there are others, often with a higher technological content, capable of providing products for specific uses and of high quality through more flexible processes; and others still, compact in size and very decentralized, for recovering and recycling scrap. Technological pluralism means acknowledging that there is not a single way of producing a good or providing a service. This makes it possible to reduce the rigidity and vulnerability of an industrial society like the current one, which has been too heavily conditioned by unanimous choices considered to be optimum.

Chapter 2

THE INNOVATIVE CYCLE

2.1. THE ECONOMIC CYCLE OF PRODUCTS AND TECHNOLOGIES

In order to fully understand how a technology and its innovative process evolve, we must consider that each product passes through its own "economic cycle", which may be shorter or longer in terms of time, but which often has clearly defined periods.

1st period: Introduction. For totally new products, there is often no specific and conscious demand by consumers. It is therefore necessary to create the market from scratch. Obviously, it is impossible to estimate in advance how long this introduction will take.

2nd period: Expansion. This occurs once the product has overcome the difficult introduction period and sales begin to increase constantly. In this period, the increase in production, necessary to meet the market demand, also allows significant manufacturing economy; thus company profits also increase. But in the meantime, it is necessary to quickly review both the marketing strategies adopted thus far, and the topics of the initial advertising campaign strategy.

3rd period: Saturation. This period, which coincides with a considerable reduction in market expansion, is essentially characterized by the demand for substitution and renovation.

The particular market where the product had been offered thus far shows clear symptoms of saturation, and it is therefore necessary to review the marketing strategy once again. For example, it will be necessary to find other markets or market segments to which to address the product (Nystrom, 1993; Stoneman, 1995).

4th period: Obsolescence. This period constitutes the last stage of the life of a product. Sales drop off sharply, and often it does not even appear to be convenient to sustain them through advertising. At times it is possible to aim the product at more traditionalist market segments, after adapting it appropriately. More often, the only decision left is to shut down the line of production.

There are two types of obsolescence:

– *technical,* when a product is obsolete from a technical and functional point of view (such as the valve radio as opposed to the transistor radio, piston-engine planes versus jet planes; etc.);

– *market,* when the product loses all or most of its demand due to changes in tastes, habits, or the lifestyle of consumers.

In many cases, market obsolescence is not a direct consequence of technical and functional obsolescence of the product. We often find so-called "*planned obsolescence*", which occurs when a company that has prepared a new model of the same product or a completely new product, for which it can reasonably predict commercial success, does nothing to revive sales of the product to be eliminated. Instead, it does its best to accelerate its exit from the market, to avoid any dispersion of the demand. This tactic is usually adopted by many car manufacturers, who tend to launch new or renovated models each year and thus aim to stimulate a lively demand for replacement of the product.

Even a specific technology, after being developed, begins to gain success and spread gradually as its development advances; this is mainly manifested as an increase in productivity and reduction of average unit costs of production. But since this pattern has a limit, and further increases in productivity may be achieved with an increase more than proportional to the investment and management costs, at a certain point its convenience ends, along with its driving force. At this point the conditions exist for the introduction of a new technology, which thus begins its own life-cycle, ending the cycle of the one it replaces.

Among other things, any company that introduces and uses a given technology can determine the limit of advantage of "intensifying" the technology itself, which may be achieved through growing levels of automation and incremental innovation. Economic advantage mainly depends on the correlation: unit production cost/productivity modification/input efficiency modification/quality modification/product mix modification. In fact, the results of technological innovation may be evaluated through the increase of productivity as well as of input efficiency, quality levels and products diversification degree.

This means that in the present hystoric phase the innovations are oriented not only towards productivity — as it had been for decades — but also towards all the aspects of a production activity. Sometimes the enterprise will get improvements only in productivity, some times in input efficiency, some

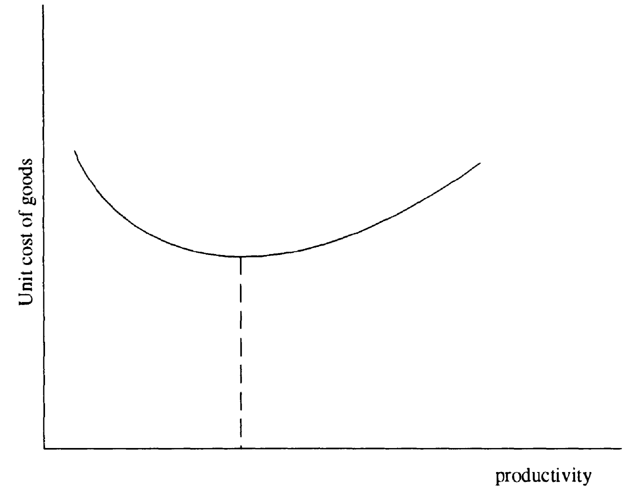

Figure 2.1. Pattern of unit cost of goods, based on productivity

others only in quality and product mix, or at the same time in productivity, efficiency, quality and product variety.

The traditional economic principle has connected technology intensification with productivity increase (Domar, 1961). The foundations of this are that in a first phase productivity increases at a rate more than proportional to overall cost increase; consequently, the unit production cost decreases. In a second phase, productivity increases at a rate less than proportional to overall cost increase; therefore the unit production cost increases (see Figure 2.1).

At present, this does not automatically entail a quick replacement of this technology by a new one, because its obsolescence depends, on the one hand, on the several aspects of technical and economic efficiency of a process, of which productivity is one — even important — aspect, and on the other, on the market features and behaviour.

The complex effects of technological innovation and intensification will be thoroughly considered and discussed in the following chapters.

2.2. THE ORIGIN OF TECHNOLOGICAL CYCLES

Innovative activity is characterized by a great deal of experimentation. New techniques do not originate all at once; rather, they are developed through time. In particular, one central characteristic of the process of technological change is that its response to various stimuli tends to be of a cumulative nature.

This brings us to the next point. The temporal evolution of any system is likely to exhibit persistent fluctuations if there are time discrepancies in the reactions of its constituent parts to uncorrelated perturbations. That is, a phenomenon subject to a cumulation of random changes is generally characterized by prolonged oscillations. The crux of this thesis can be very simply explained as follows: suppose that the process under consideration involves both small and large changes. These two types of changes may well differ in the frequency with which they occur. The large changes, unless they are nullified by a sequence of small changes, are likely to give rise to a cyclical phenomenon insofar as their influence is extended far beyond the time of their occurrence because of the process of cumulation. Further, random changes may well come at times in clusters. These clusters will tend to combine with each other into a high or low level of saturation because of the process of cumulation. In consequence, each of these clusters will tend to exert its influence beyond the time of its occurrence. Thus it is demonstrably true that cumulation or averaging of a frequency distribution of a random character will not result in a smooth trend. Rather, it is expected to yield oscillations arising from the prolonged influence of large single changes or of large clusters of changes pursued by a sequence of smaller changes or of smaller clusters.

As remarked earlier, the process of technological change is not entirely random in character. It is indeed characterized by a secular trend. We can therefore conceptualize it in terms of a skewed distribution. The skewness of the distribution will then account for the existence of a secular trend in technological activity. In addition, however, the process will be subject to (possibly recurrent) oscillations arising from the cumulative operation of the underlying causes.

A priori, therefore, the existence of recurring fluctuations in innovative activity is not unexpected. The implication is that the process of technological development involves two phenomena of change. First, there exists the phenomenon of persistent long-term growth characterized by the existence of a certain development trend. Second, as noted here, a priori, there also exists the phenomenon of recurring fluctuations. These two types of phenomena are distinct but related. For example, it is not implausible that an understanding of oscillations in the innovative activity is essential in order to account for the continuity of the activity as a whole. It may also provide a framework wherein the growth and stagnation of technology can be systematically analyzed.

2.3. ENDOGENOUS AND EXOGENOUS PARAMETERS PROMPTING THE INNOVATIVE CYCLE

A number of elements interact to prompt the innovative process: the needs of users, the status of knowledge and technologies, the market structure, the resources available to those who adopt an innovative process, the system of relative prices and environmental conditions in general (Vincent, 1961; Blaug, 1965; Davies, 1979; Cooper, 1994).

It is generally agreed that the main variations in the rate and direction of inventiveness are influenced by socio-economic forces. As Utterback (1974) reveals, the innovative potential of any business may be considered a function of its environment, including economic, social and political factors, the state of technological development and information concerning the technology.

However, there are differences of opinion between those who prefer to attribute innovation with a scientific motivation or see it as being pushed by the technological opportunities that have arisen in one sector rather than another (the "Technology Push" theory) and those who feel it to be a consequence of demand (the "Demand Pull" theory).

From the first interpretation, it derives that the new products and processes are generated first and foremost by progress in scientific knowledge.

The second view is instead related to the old adage that "necessity is the mother of invention", and maintains that the opportunities created by the changing configuration of demand, especially high costs or scarcity of inputs that obviously affect profit margins, are what determines the entity and orientation of research.

One supporter of this theory was Schmookler (1966), who set out to prove it with two empirical tests. In the first, an analysis of the most important inventions produced over the last two centuries in four branches of American industry (paper, railway, agriculture, oil refinement) shows no scientific component. In the second, in which he considers patents of capital goods by industries, the comparisons of historical series and data from various countries show a high correlation between the number of patents and the volume of investment.

The changing frequency of innovative processes does not precede the growth or decline of investments, production and profits, but is simultaneous with them. This correlation is explained by the hypothesis that the research activity that leads to innovation is basically stimulated by the expectations of profit which depend, in turn, on the volume of the formation of

capital and thus expected sales, meaning demand. The decline in innovative activity in a sector would then not depend on a lack of technological opportunities in the sector, but rather on the decline of profit opportunities that may be gained with respect to the future pattern of demand.

Companies tend to innovate first in areas where there is a clear potential for short-term profits.

Schmookler's theory did not appear to be fully convincing, nor were his empirical tests considered to be sufficiently meaningful (Schmookler, 1966).

The accumulation of scientific knowledge inherited from the past, and not its specific increase, would be a necessary condition in some cases, and in some cases would facilitate technological innovation, but it would never be a sufficient condition if the support of demand is lacking.

This formulation does not grasp the dependency of innovation on the dynamics of scientific progress, nor does it leave sufficient room for the delay that exists between progress in pure research and the necessary improvements required before arriving at a patent that regards the invention in its solely commercial applications.

The number of patents is not representative of innovative performance (Momigliano, 1975; Raggi, 1993).

In addition, in Schmookler's scheme demand appears to be exogenous, and thus incapable of taking into account the effects of advertising and the artificial creation of demand in general; this leads to the risk of certain inventions being considered induced by the demand, when the demand in question has been deliberately developed to absorb the sale of some new product of scientific discovery: the businesses in which technology makes the most rapid progress are those most capable not only of producing technological innovations, but also of finding new and more efficient markets where they can place the fruits of their talent (Pavitt, 1973).

At the foundation of the "demand pull" theory lies the conviction that society has a highly flexible basic knowledge, virtually usable for developments in all directions; this leads us to conclude that the stock of scientific and technical knowledge is sufficient in order to allow the invention of new products and processes whenever the demand "pulls" enough, and the yields of research promise to be sufficiently high.

This point has been contested by Rosenberg (1970), who maintains that science and technology evolve, at least in part, according to their own internal logic, independent from economic forces. It is this sort of internal logic

that conditions the times and directions of innovative applications, also because it leads to different limitations and costs at different times and in different industries.

Recently, a very significant situation has arisen of important innovations prompted by the needs of supply and those of demand, simultaneously: that of "energy efficiency" and "environmental efficiency".

Two studies specifically prepared and conducted on significant worldwide industries (steel, aluminum, chemical industry, building materials, paper, glass) have made it possible to establish that increased energy and environmental efficiency in production processes cannot be achieved simply by "adjusting" the processes themselves, but rather require a radical change in the basic schemes.

This can be done by simultaneously improving productivity, product quality and, often, flexibility.

This leads to the achievement of a new type of "global efficiency" of processes, with economic benefits so high that they rapidly recover the costs required by the innovations.

In addition, these new criteria do not stop being applicable to a single industry, but to the extent to which they are valid, spread among various industries in different branches of production.

In this sense the "energy and environment" factors stimulate considerable technological innovations (Barbiroli, 1993a, 1993b).

This has occurred — and is still occurring — for "supporting and strategic" technologies, such as: casting and continuous-drip techniques, plasma arch furnaces, vacuum and controlled-atmosphere furnaces, fluidized-bed furnaces, heat regeneration furnaces, direct-contact heat exchangers, diaphragm separation systems, laser systems.

The cases analyzed and described are indeed a concrete example of how innovation can be done, by combining the needs of the community (rational use of resources, environmental balance, development) with those of the company (efficiency and competitiveness).

At the opposite extreme, the "technology push" theories tend to consider technological progress as an original cause: research and development programmes and high rates of innovation exist only when there is a sustained and exogenous scientific progress. If the progress of science declines or moves in directions that lead to few technological opportunities, then technological progress moves slowly. The role of basic science is reflected in interindustrial differences, both in R&D work and in the output of innovations.

The acceptance of this concept and a rejection of "demand-pull" would not only preclude the explanation of invention as an economic phenomenon, but would also reject any influence of the market structure on innovation.

We might attempt to join the diverging viewpoints by acknowledging that the inventions perfected represent a point of intersection between the set of scientifically possible innovations and the set of economically advantageous innovations. Yet this would not eliminate the problem, since changes in the intersection set may be caused mainly by the development of the set of possible innovations, overlapping the set of advantageous innovations, or vice-versa.

Neither of the two theories is alone capable of interpreting all innovative developments found in reality.

It has been noted (Momigliano, 1975) that the "demand-pull" theory may be used to explain development in traditional, mature sectors, whereas the theory of technological opportunity is more evident in "research-intensive" sectors, where there is of course some influence by demand, but a special type of ex ante demand, not market demand, such as military and aerospace research.

In general terms, in the debate between supporters of the "demand pull" or "technology push" theories, it appears that we may in the end accept an intermediate hypothesis: that the action of both mechanisms coexists in modern industrial systems, and prevails according to the type of industry.

2.4. INNOVATION AND COMPANY SIZE

Since research requires the availability of special technical-scientific equipment and personnel, it is reasonable to assume that certain results may be achieved only after certain investment threshold values have been crossed; these values may be critical for less economically and financially solid companies.

One supporter of the need for large companies is Galbraith (1968); as a matter of fact, technology require the size, financial capacity, means and market control instruments of large companies in order to achieve innovation.

In particular, it is not so much the costs strictly for research related to innovations that are out of reach for small companies, but rather those related to developing the inventions, thus those to be sustained in order to perfect an innovation until it is commercially usable (there is a rule for calculating

the development cost of an invention: this cost is approximately 10 times the cost of the basic invention).

Another point that is often invoked in favour of large size is related to the high risk of Research and Development activity. This implies, first of all, that a business can be reasonably certain that it will obtain positive results from research only if it is able to finance various projects simultaneously, and if it can afford to wait for some time before reaping the benefits that may derive from it. Utterback estimates a time lag varying from 8 to 15 years between the time an innovation is available and the time it is used in a commercial application (this period varies according to the industry involved, the type of product, the type of market and resources used).

However, some projects will not lead to the anticipated results, but others will achieve a success that compensates for the losses sustained in the failure of the former. Or, the delay with which a research project produces positive economic results for the company may be compensated for by the profits made following the success of other projects.

Furthermore, Momigliano (1975) points out that R&D on a number of projects provides increased opportunities to use the various sub-products of the results of one project in others, even if the results of that project were not successful.

Another argument in favour of large size concerns the concept of economies of scale. It is well known that the production of any product may be economical only with certain productive dimensions, which must in practice be fairly high.

From the standpoint of potential innovative capacity, the large company is generally at an advantage over smaller companies as it has greater possibilities to finance a research activity, both with its own capital in the form of undistributed profits and with loan capital, since it has easier access to public financing and financial markets.

Based on empirical studies carried out by Mansfield, it does not appear, however, that large companies spend a decidedly higher percentage of their turnover on research than medium or small-sized companies, when the latter undertake research projects.

This result is one of the arguments of the theory opposing that of the large-sized company does not demonstrate a greater ability to generate and use innovations than a smaller-sized company.

Large-sized companies do not appear to develop a greater proportion of innovations in relation to their market share with respect to small companies;

based on studies by Myers and Marquis (1969), it appears that no logical relation exists between the size of a company and the number of innovations.

But this is forcing the theory. Other authors (Markham, 1975) state that innovative efforts tend to increase in greater proportion to company size up to a certain point, which varies from branch to branch. For companies larger than this limit, the intensity of innovative efforts appears to remain constant or fall as company size increases.

Mansfield summarizes by saying that up to a certain threshold, which varies from branch to branch, innovative efforts increase in greater proportion to size; once this threshold has been passed, innovative intensity not only does not increase, but often decreases with size.

The Myers and Marquis theory (1969), which states that there is no logical relationship between company size and innovative activity, refers to the capacity to generate inventions, which is different from the capacity to develop innovations or commit resources to R&D activity.

Due to the economies of scale that can be achieved in research, it is not the percentage of turnover spent on research that is relevant so much as the absolute level of these expenditures; from this viewpoint, the advantage of the large company is obvious.

In this regard, Mansfield (1968) has found that the most important innovations are not achieved by large companies, but are rather the fruit of independent researchers who act individually outside of them. Very often, the innovative activity produced by large companies is based on improvements in innovative processes and products created outside of them.

This leads to the reduced ability to generate innovations: thus the most important discoveries rarely originate in the laboratories of large companies. Much of the research carried out by these companies is not aimed at developing products with a radically different concept from those present, or such that require basic notions other than those normally necessary for manufacturing existing products. This is true because, in order to reduce the high risk of research, companies tend to stimulate research into areas whose general characteristics are known, and thus where there is a good chance of achieving results that can be used in the production activity.

We should also note that, alongside the economies of scale that can be achieved by organizing research in large company laboratories, organizational diseconomies can also originate. Firstly, there may be limitations that appear in setting up research in groups, especially those with a large number of members. But mainly, in large companies more bureaucratic obstacles are

encountered and the environment is more formal, which reduces the creative sense of the researchers. However, to prevent the bureaucratization of large industrial groups, it is always possible to decentralize research activities into smaller operative units, without losing useful financial connections and a good degree of technological integration.

Yet it is not easy to use empirical analyses to prove the greater or lesser innovativeness of large companies with respect to medium-small companies, since the results vary considerably depending on the sampling, the level of aggregation, and the methods used.

2.5. INDICATORS OF TECHNOLOGICAL INNOVATION

Various technological indicators have been proposed in economic literature with the aim of giving a measure of technological innovation. Even though technological innovation has to be considered a single process, the technological indicators proposed in the literature are divided into input indicators and output and impact indicators (Freeman, 1969).

Input indicators measure the factors involved in producing technological innovations, and they mainly concern the amount of human and financial resources devoted to research and development activities; R&D expenditures are the most important indicator of this kind.

Output and impact indicators are intended to give a measure of innovation through the effects and the results which it produces. Output and impact indicators can be classified into:

- statistics on patents;
- technological balance of payments;
- statistics on innovations (direct surveys);
- trading in high-tech products;
- scientific output indicators;
- other lesser indicators.

It should be pointed out that only two among the proposed indicators (statistics on R&D expenditures and direct surveys on innovations) were specifically created for the measurement of technological innovation, while the others were adopted from other fields of application.

a) Research & development expenditures. Statistics on R&D expenditures present some limitations as a technological indicator. First of all, R&D does not necessarily yield innovation. On the other hand, activities other than for-

mal research (e.g., learning by doing) may be determinant in producing incremental innovation (Rosenberg, 1982). Therefore, R&D expenditures are not the only source of innovation.

Moreover, R&D may assume a different importance according to the industrial sector and the firm size. Some sectors (e.g., electronic, pharmaceutical and chemical) present a more formal and more easily quantifiable research activity than others (Archibugi and Sirilli, 1985). Large firms have a higher R&D intensity than smaller ones, as the former usually formalize their innovation activity as laboratory research, while the latter do not (Kamien and Schwartz, 1982; Soete, 1979). Thus, sectors with a high firm concentration level may have higher R&D expenditures than others.

b) Statistics on patents. Patent statistics are considered by most authors to be an interesting and sufficiently reliable technological indicator. These statistics are made available by patent offices, some international organizations and information processing firms. Centres gathering national and international data bases on patents exist in many OECD countries (e.g., the U.S. Office for Technology Assessment and Forecast).

Despite their widespread use, patent statistics present some limitations which do not allow them to be a fully reliable indicator of technological innovation. Some of these limitations are even recognized by the authors who use patents as a technological indicator. The first limitation is that not all inventions are patented, and not all patented inventions develop into innovations, especially when the patentee is a private individual and not a firm. Secondly, even if a patented new process or product is adopted as an innovation, a certain time lag occurs which does not show up in patent statistics. This phenomenon is referred to as "sleeping patents". Finally, the patenting trend is not the same for all industrial sectors and types of inventions. Where imitation is more likely, patenting intensity is higher, but it does not necessarily correspond to a higher innovation rate.

c) Technological balance of payments. The technological balance of payments (TBP) measures the financial flows deriving from transactions of industrial and intellectual property rights, such as patents, licenses, technical assistance and know-how.

TBP, as well as R&D expenditures and patents, presents some limitations as a technological indicator. First of all, since TBP is only concerned with transferred technology, it does not take into consideration all those technological innovations which are the object of no commercial transactions, or which are exchanged without any financial transactions (as in the case of

patent swap or cross-licensing agreements). Secondly, since only international technology transfers are recorded, innovations which are transferred within a country are excluded. Moreover, multinational corporations may greatly affect TBP transactions while operating their global cost or profit strategies. TBP transactions, indeed, are strongly concentrated in a small number of firms. It should be pointed out that TBP payments and receipts are seldom recorded when technology transfers take place; when technology is transferred, the counter-value may be only partially paid at once and, then, be settled later, normally by several payments (e.g., royalties). Thus, TBP financial transactions recorded in a certain year may refer to technology transfers that occurred previously.

Furthermore, when technology transfers are directed towards newly industrialized countries rather than developed countries, they may not refer to innovative technologies but to mature ones instead.

Finally, the transactions included in the technological balances of payments of the various countries are not the same; besides technology transfers in the strict sense of the term, technical services (consultancy, transfer of experts, market surveys, personnel training and teaching) or transactions not directly related to technology (trademarks, management services) may also be involved. Moreover, international comparability may be limited by the different survey procedures and by the way data are processed and published.

d) Direct surveys. Instead of trying to measure innovation through technological indicators, it might obviously be possible to quantify it through direct surveys. Unfortunately, the complexity of technological innovation and the difficulty in defining it precisely makes this kind of operation difficult to realize. Methodologically, there does not yet exist an accepted procedure for carrying out such surveys; however, some studies have been made which may form the basis for further developments.

Surveys on innovation were conducted in Italy (ISTAT, 1987), France (Piatier, 1983), Germany (Institut für Wirtschaftforschung, 1983), the UK (SPRU, 1981) and the U.S. (Acs and Audretsch, 1988).

e) Trading in high-tech products. Data on trading in high-tech products represent a quite recently proposed technological indicator, and consequently it is still being defined. The use of this indicator requires the definition and identification of high-tech products.

Despite several studies carried out on this subject (Amendola and Perrucci, 1988; Vernon, 1966; Pierelli, 1983), there still remain a number of un-

solved problems, particularly concerning the product classification procedures (difficulty in identifying the appropriate ranging index, the subjectivity of fixing index threshold values for low, medium and high technological intensity groups). Moreover, such classifications do not generally take into account the indirect technological contents of products, that is technology embodied in the production factors employed.

f) Scientific output indicators. Unlike the other output indicators examined, which are concerned with the results of scientific-technological activities (mainly performed in industry), these indicators intend to measure the output of fundamental research, which is mainly carried out by academics.

The most well-known and widely used among these indicators are bibliometric indicators (scientific publications and citations) and "peer reviews". The former are based on the number of publications, citations and co-citations referred to in scientific works; the later consists of the evaluation of scientific works made by other scientists and researchers.

While these indicators may be useful for the assessment of the status and perspectives of science in a country or scientific branch or institution, although some limitations have been pointed out, they can hardly be suitable for measuring technological innovation.

g) Other lesser indicators. Finally, there are a number of minor indicators which can only marginally express the status of science and technology in a certain productive sector or country such as capital investments, productivity and industrial performance indices.

As we have seen, several indicators have been proposed and, although some of them have been used in a variety of applications, each presents some limitations — often acknowledged by their proposers themselves — which may raise doubts on their full reliability. In a recent study (Raggi, 1993), in order to analyze their behaviour, some indicators were tested by applying them to the measurement of innovation growth for 20 product groups of the Italian economy. The indicators employed were one input indicator (R&D expenditures) and two output indicators (patents and technological balance of payments), which are generally considered the most mature and reliable ones.

The results have led to the conclusion that the adoption of a single indicator for the measurement of the technological growth rate is hardly acceptable, and no assertion about innovation levels can be made unless concordant information is obtained by various indicators.

2.6.TECHNOLOGY TRANSFER: TIMES AND COSTS

The innovative cycle is very complex and it follows several stages and patterns, which have been clearly described and analyzed by several authors (Sahal, 1977; Amendola and Gaffard, 1988; White, 1988; Copp and Zanella, 1992; Szakony, 1992; David, 1994; AMACOM, 1995; Audretsch, 1995).

Innovation must be distinguished from invention and the technical prototype, as it refers to technology used or applied commercially for the first time.

Between the time an invention is available and when it is used in a commercial application there is a wide interval, which varies in relation to the type of industry, the product, the market and the resources used.

Utterback (1974) estimates that the interval appears to be shorter for innovations aimed at the consumer goods market (the opposite of industrial goods) and for innovations developed by public agencies (as opposed to those developed by private industry). However, given the small sample analyzed, these conclusions have limited validity.

Table 2.1 shows the elapsed time between the date of the final invention and that of commercial introduction for some historical goods.

Basic research is not a direct source of innovation, but takes on a fundamental role in the production of knowledge and indirectly influences the innovative process. Its role is in part responsible for the innovation time lag.

The average lag indicates the ability of different technical-economic systems to create economic progress. Countries which generally show a shorter lag are usually more capable in that sector than others. A shorter average time lag means a high rate of technological innovation and greater ability to respond to changing market conditions, thus allowing better economic performance in terms of higher industrial development and increased competitive skills.

At present, there is a substantially shorter lag in Germany and Japan; this indicates a more stimulating environment for technological innovation with respect to the U.S. and the United Kingdom.

In light of the high competitiveness of German and Japanese products on the international market, these results tend to emphasize the ability of the average innovation time lag to indicate the relative innovative capacity of the various countries.

Observing the development of a new product or procedure from the planning stage to market entry, we can note that a business encounters its main difficulties in the following areas:

TABLE 2.1. Estimated time lag between invention and innovation for some important innovations

Innovation	Date of final invention	Date of commercial introduction	Development time
Telegraph	1838	1844	6
Frozen foods	1842	1925	83
Electrical arc lamp	1845	1859	14
Sewing machine	1851	1853	2
Typewriter	1868	1875	7
Telephone	1876	1879	3
Aluminium	1886	1892	6
Mechanical cotton picker	1889	1942	53
Wireless telegraph	1889	1897	8
Automobile	1891	1895	4
Wireless telephone	1900	1908	8
Synthetic resins	1907	1910	3
Synthetic rubber	1909	1940	31
Titanium	1910	1950	40
Radio	1912	1920	8
Vitamins	1913	1937	24
Electronic computer	1919	1950	31
Television	1919	1941	22
Nylon	1928	1939	11
Plexiglas	1929	1932	3
Numeric control	1930	1955	25
Turbo reaction engine	1934	1944	10
Ball-point pen	1938	1944	6
Synthetic leather	1938	1964	26
DDT	1939	1942	3
Semiconductors	1941	1951	10
Integrated circuits	1955	1961	6

– documentation;
– management and specialized personnel;
– infrastructures (for instance, laboratory equipment);
– financing.

The documentation and financing of an innovation project are often clearly inadequate (Repetto and Heaton, 1993; Jeremy, 1994). An analysis of the obstacles encountered by companies leads us to conclude that the desire for innovation by many companies is impeded mainly by the difficulty of finding concrete applications for technological knowledge, and finding risk capital. Experts and farsighted managers are necessary in order to realize a project, as well as technical equipment and assistance at an acceptable price. In order

to convince the company executives, who are often not professional technicians, of the usefulness of an innovation, it is necessary to use business planning tools. Market research and risk analysis may offer a valid contribution, as decision-making criteria for planning (Quince, 1993).

Technology transfer is very often complex, and it is a widespread opinion that technology cannot be exported as easily as some countries might assume (Seurat, 1977). It is however possible, in general, but certainly on the condition that one knows how to take advantage of time to make progress in the complexity, admit the need to be masters of the behavior, reactions and ability to build a machine, before having the ambition of conceiving one. Seurat emphasizes that, in this way, the fundamental importance of communicating practical knowledge (Machlup, 1962) is obvious in the work, decisions and action in a certain process when transferring technology.

The efficiency of the transfer mechanism thus depends largely on the level of communication that the parts are able to achieve: information transfer is a necessary prerequisite for an effective technology transfer.

On the same topic, Arrow (1969) suggests that the cost of communication or information transfer is a basic factor affecting the world-wide diffusion of technology.

In order to understand the definition of "cost of communication", we should recall the distinction between the two forms assumed by technology in transfer: hardware (or capitalized) technology, regarding the supply of machinery-tools, equipment and designs where the technology is built-in, and software technology (alienated or interiorized) which is transferred for the practical use of hardware: information regarding the maintenance and organization of production, quality control, know-how and other production procedures.

The actual transmission of this peripheral support is the crucial point of the technology transfer process, and leads to a relative flow of information (Teece, 1977).

The cost of the transfer and absorption of information is represented by the cost of transferring this "non-capitalized" (unembodied) knowledge, and is only a percentage of the overall cost of the transfer (percentage of the overall sums and royalties).

In practice, the cost of information forms the synthesis of four groups of specific costs.

The first group is the cost of pre-engineering technology exchanges, where the basic characteristics of the technology are bought from the seller, and the necessary theoretical skills transmitted.

The second group includes the engineering costs associated with transferring the design and the process engineering in the case of process innovations, associated instead to designing and engineering the product in the case of product innovations.

The third group of costs contains R&D expenses (salaries to personnel involved in R&D and others) during all stages of the transfer project. These are not the costs associated with developing the underlying product or process innovations, but those sustained in order to solve unexpected problems and to adapt and change the technology. For instance, research scientists may be used if new and unusual technical problems arise during the transfer, in relation to the input adopted.

Finally, the fourth group consists of the pre-start-up training costs and excess manufacturing costs, thus the costs of the apprenticeship and debut during start-up, before the plant achieves its specific "actual mastery in carrying out the functions related to a technique" anticipated in the technology transfer schedule. It is possible that no saleable items be produced during the initial start-up period; however, there will be costs for labour, materials, and depreciation, in addition to costs for the supervisory personnel essential during start-up.

The number of factors that affect the cost of information transfer is undoubtedly large, but some have a greater influence.

In international technology transfers, different conditions, procedures and results exist according to the characteristics of the buying and selling companies and countries (Gee, 1981; Goldberg, 1978; Tavel, 1979; Lowe and Crawford 1984; Cantwell, 1994).

Chapter 3

TECHNOLOGICAL DYNAMICS AND KNOWLEDGE

3.1. INFORMATION AND KNOWLEDGE AS STRATEGIC RESOURCES

The current technological revolution has led to an increase in the role of knowledge, in all of its forms, and at increasingly high and in-depth levels, to the point that "information technologies" have become essential, requiring complex organizations and absorbing a growing number of employees.

Knowledge — of which information is the essential foundation — can determine the success or failure of any production or service activity, as it produces positive results if adequately used (Cole, 1986).

Information technologies proceed in two main directions: on the one hand, the development of products, equipment, systems and concepts (ideas, procedures), and on the other the application of these to specific areas of human activity.

The first direction is pursued by independent research centres (universities, etc.) or by firms and organizations whose purpose is to systematically increase knowledge in specific fields, in both pure and applied forms.

Many research activities require considerable financial resources to cover the costs of scientific equipment, personnel, and organization, and few have access to such resources. This means that the potential to increase knowledge is available to a limited number of individuals/organizations who, therefore, can take direct advantage of the results achieved before this knowledge spreads.

Since the modern company benefits from advanced, in-depth knowledge, knowledge must be considered a true "strategic resource".

The second direction — application — is pursued by all organizations and individuals to satisfy specific professional or recreational needs. It includes acquiring information to expand knowledge, preparing a project aimed at achieving the desired goals, and finally executing the project, thus applying knowledge. This knowledge must be further expanded and deepened in the management stage and in the development and improvement stages that must inevitably follow in order to adequately satisfy growing

needs and remain competitive. Therefore, strategies of diversification, and thus the adopion and handling of flexible systems, require knowledge first and foremost, at every level, in order to continue to increase their chances of success.

Both directions mentioned above require that the level of knowledge available at any time and place be constantly known, as well as what has been and is about to be introduced and applied, the evolutionary trends of knowledge, and even what is felt may be known.

To make all of this possible and convenient, public institutions and agencies and private individuals and organizations have intensified their efforts, especially in recent years, to acquire and make available the knowledge that is gradually "produced and processed".

It is no coincidence that the advanced industrial societies, which are experiencing the new technological and industrial revolution, are also known as "societies of knowledge".

However, it must be pointed out that while information and knowledge are fundamental in order to provide concrete and economically positive results for those who intend to use them, they must be subjected to in-depth, sophisticated processing; in addition, their value and usefulness must be critically known, in order to include them in the situation for which they have been acquired, together with all others felt to be useful.

Therefore, the choice of information, its critical analysis and evaluation of the opportunities it creates are increasingly important.

3.2. SOURCE, QUALITY, COST AND VALUE OF INFORMATION

We all expect information to be reliable and accurate. In other words, information should be in agreement with reality. The reliability of information is increased if it can be verified. Moreover, information must be sufficiently up-to-date for the purpose that it is to be used. It must be complete and precise, allowing the recipient to select specific details according to need. If incomplete, the degree of uncertainty must be indicated, or else it should follow some well-recognized convention. Information must be intelligible, that is, comprehensible to the recipient. Again, there are rules, conventions and assumptions (of language, or symbols, etc.) which when obeyed ensure this aspect of the quality of information. These general characteristics of high-quality information may not be present in practical instances.

Low-quality information can actually be downright misleading or distorted (as a result of the deliberate action of the source, or of the transmission process). It may be inconsistent with other information. It may be poorly presented, or even incomprehensible to the recipient. A point worth making here is that many information technology products are aimed at detecting and, if possible, improving low-quality information before it reaches the recipient.

In addition to the general characteristics of high-quality information (such as one would expect from a public broadcasting or news service), there are certain desirable features associated with specific uses of information. For example, when a response is given to a well-specified inquiry, it should be relevant and timely; it should be in a form which is conveniently handled (interpreted, classified, stored, retrieved, updated, etc.) by the recipient; it should be of the appropriate level of detail and, if necessary, adequately protected (e.g., coded or the access to it controlled). People also appreciate if information is presented in an interesting and friendly way.

Four features affecting the quality of information are: accuracy, content (the breadth or scope), recency (up-to-dateness), and frequency of presentation. Content is considered the most important, followed by accuracy.

On a more general level it has been stated that what people are prepared to pay money for is exclusive information and/or predictive information, the first being information tailored to the needs of the recipient, and the second enabling the recipient to select a particular action out of a whole range of possible actions. We can add to this that the perceived value of predictive information relates to the subjective value of the outcome of the selected action. For example, information on train departure times becomes the more valuable the more crucial the purpose of the journey. Thus, the value of information is not an inherent or constant quality. It depends on the needs of the recipient and on the use to which it is put.

In the most general sense, information is valued for its organizing power. High-quality information enables the recipient to make sense of the environment and to take action necessary to cope with changing circumstances.

One fundamental point is the necessity to make an objective comparison between the value of acquiring some piece of information and the cost associated with the acquisition process (Feeney and Grieves, 1995). The cost of information is attributable to two main components: the intellectual labour involved in originating and handling it, and the non-human element made up by processing and storage equipment, distribution methods, etc. The non-human costs are usually easier to quantify: it takes a certain

amount of energy to form and transmit a representation of information, be it the spoken or written word, broadcast transmission, etc. If some physical record of the information is required, it also takes a certain amount of material to act as the carrier. Thus, a book or a magnetic tape, for example, would have some inherent cost, quite apart from the production cost of the information which it includes.

When information is replicated in large volumes and is recorded on some physical medium, as would be the case with newspapers, books, records, etc., the cost of the medium may well dominate the unit cost of the information-plus-medium. In such a case, the total product becomes a commodity, in the economic sense of that word.

3.3. KNOWLEDGE AND INNOVATION

As it has already been amply illustrated, knowledge is the foundation of every innovation; this is clearly shown in the diagram in Figure 3.1.

The idea with which the innovative process originates is generated by starting from an examination of market needs and technological possibilities; it must be verified whether it is technically possible to satisfy new needs, and identify market demands that can be met through new technologies. An examination of the market needs and technological possibilities requires the availability of abundant information and documentation. Similarly, information is also necessary in order to evaluate the social acceptability of the innovation to be produced; failure to take into account social changes and their impact on the technological innovation can indeed jeopardise the success of the innovation itself.

All of the stages of the innovative process, however, are joined by means of a complex network of information flows, originating both internally and externally (Davenport, 1992; Ciborra, 1993).

Table 3.1 shows the different specific inputs of knowledge, and thus information, required at each stage of the innovative process (Stern, 1982).

We should remark upon the primary role of research and development in the innovative process, and professional skill in handling it. Both are the driving and decisive element that makes it possible and convenient to realize any innovation, large or small.

The role of those who deal with research and development, in particular, should consist of:

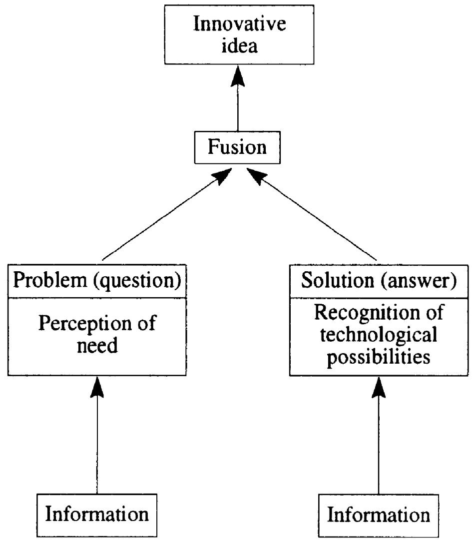

Figure 3.1. Diagram of procedures for the generation of the innovative idea

- keeping scientific and technological developments under close observation;
- representing an interdisciplinary pole that groups together a variety of disciplines;
- attempting to minimize the costs and efforts required in applying scientific and technological knowledge;
- being especially active in the process of transferring results from one's own research work;
- being able to objectively evaluate the feasibility of an innovative project.

All of this leads to the need to have a considerable amount of information available. This need may be satisfied through various means: the main ones are the organizing of an internal library to store texts and scientific journals, and the use of an outside information service which gathers information and selects and interprets it on the basis of the user needs (these services might include documentary and bibliographic data banks).

Knowledge, in its various forms has made it possible — and will continue — to innovate sectors considered to be mature, even transforming them from manufacturers of conventional goods to manufacturers of functional goods, whose use requires yet more specialized knowledge.

In Italy, significant examples include the Prato textiles industry, the steel industry, and the ceramics industry. Of course, even advanced sectors are changing dramatically, with an increased prevalence of the immaterial component over the material.

TABLE 3.1. Information inputs for innovation

INNOVATION PHASE	INFORMATION INPUT	
1. AWARENESS, IDEA	EARLY WARNING SYSTEMS	Monitoring journals, reports, practical experiences Opportunities, threats and restrictions New needs and aims
2. PROJECT DEFINITION	EXTERNAL INFORMATION	Market Economic Political and social (employment, life standards, etc.) Technological
	INTERNAL INFORMATION	Project records Staff expertize Technological capability Internal data Reference library
3. R&D: SITUATION APPRECIATION, DECISION ON METHOD	EXTERNAL R&D	Literature searches Literature alerting Patents and standards
	INTERNAL R&D	Prototype studies Systems development
	FEASIBILITY STUDIES	Technological capability Market and economy Socio-political impact Resources and environmental impact
4. DESIGN	PRODUCT SPECIFICATIONS	Design specifications Testing procedures
5. PRODUCTION	TECHNOLOGY	Appropriateness New technology Staff training Material studies Quality strategy Environmental strategy
	IN-PROCESS DEVELOPMENT	Design changes Production changes Maintenance procedures
6. MARKETING	EXTERNAL INFORMATION	Resources and Environment Market Economic Socio-political

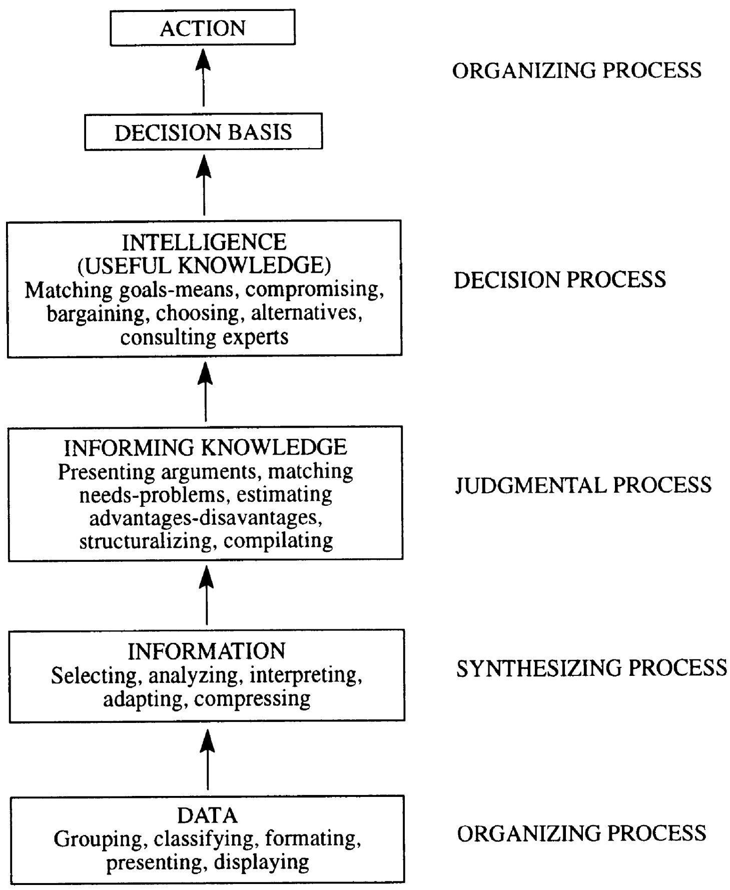

Figure 3.2. Main steps in the process of refining information

Main examples are the chemical industry — especially the fine chemicals — the car industry, aeronautics, and many others.

In order for all of this to occur, however, it is essential for the role of knowledge to be adequately recognized, sufficient resources must be set aside for the organization of information and documentation services and attempts made to remove all of those barriers — such as prejudices, language, culture, time, interference (noise) — that interfere with the dissemination of knowledge.

Knowledge represents learning acquired through teaching and experience. In order to be used, it must be subjected to a refinement process that includes various stages.

Figure 3.2 shows how the original data are refined into information, through organization and synthesis, and then into useful knowledge, through integration and evaluation.

The initial stages of this refinement process are made much more efficient today, thanks to the availability of automatic information processing systems. The future development of so-called fifth generation computers and languages for artificial intelligence will make it possible to automate the entire process.

3.4. ACTION AT THE NATIONAL LEVEL TO SUPPORT INNOVATION

The question is often asked whether governments at the national level have an obligation, in a free enterprise society, to provide innovation support measures, including advisory, information and documentation services, to industry. In many countries the answer is affirmative, especially as far as support to small industries is concerned.

We may state that the national government should support innovation by means of government contracts, the establishment of technology transfer points, advisory services, and the support of documentary information services and the encouragement of industry to use external research and development and external information resources.

To this one could add productivity institutes, production engineering advisory services, low-cost automation centres, technological institutes (as opposed to high level research institutes). It is clear that, in principle, a formidable array of innovation support activities at the national level can be listed, and that many of these rely on the supply of scientific and technical information. Even teaching courses on technological innovation, e.g. at industry-university co-operative centres, is advocated (Nelson, 1993).

Indeed, in one form or another, such services now exist in most industrialized countries and in several developing countries. Some have grown as a result of individual initiatives, others have been, or are being planned, as an outcome of national information policies, or they are seen as part and parcel of measures to be taken in terms of technological innovation policies (Teitelman, 1994).

The kinds of measures taken in individual countries depend on traditionally held views in these countries. In the USA, the intention is to stimulate innovation by removing obstacles, while in other countries direct government involvement — e.g., in the form of subsidies for industrial R&D — based upon selective industrial strategies, as well as the introduction of other innovation support programmes, is advocated.

The importance of information is particularly relevant in the case of small-sized and medium-sized firms, which do not have their own R&D or information facilities. Yet, such firms can make important contributions to technical progress. The OECD, in a recent study, has suggested a number of government policy orientations to support the innovative capacity of small-sized and medium-sized firms. These include the establishment of information networks, as well as training and technical assistance facilities.

The fact that small-sized firms can be important contributors to industrial innovation is, of course, not new.

Several western countries, as well as Japan, have established, or are in the process of establishing more or less formalized national information policies. In some cases (France) the accent has been placed deliberately on scientific and technical information for industry. The question may be asked whether those policies, where they have been in operation for several years, have been successful.

3.5. THE ROLE OF TECHNOPOLIS IN TECHNOLOGICAL DYNAMICS

In the presence of complex and costly modern technologies, it is no longer possible to close oneself off, finance one's own research and reasonably hope to achieve success: it is necessary instead to search out allies even from among competitors. In new industries, the material bases are no longer national or continental, but global, and the same is true for technological and scientific wealth. By now we may refer to global enterprises, capable of penetrating world markets simultaneously, and which arrive at agreements with other enterprises in order to achieve this goal.

Since innovation takes place by contamination, horizontal connections, cross-fertilization, it is necessary to put together resources and structures functional to its circular nature. This is the case of immaterial resources such as knowledge, information, creativity, and the structures of higher education and scientific and technological research.

The new roads of innovation run through technopolitan places: intellectual production centres governed by hybrid logistic and organization instruments, a mixture of public and private, to facilitate the creation and marketing of innovations. Meeting places, not only professional but social, between mutant subjects, both organisms and individuals. In a convivial cli-

mate, freed from the rigid confines of Taylorism, they could give free run to their imagination. To conceive *creative* environments thus becomes one of the buzzwords of technopolitan projects.

In the technopolis, however, creativity is not an end in itself. It is instead part of a broader and more ambitious design aimed at offering new, solid foundations for innovative initiatives. Its purpose is to stimulate innovation related to commercial applications, and encourage the launching of new products. New forms of multilateral agreements between researchers and scientists, potential entrepreneurs and new, innovative businesses, small and medium-sized innovating companies, large multinationals, all find here a new testing ground, as well as the development of company processes for internationalization.

The creation of technopolitan sites may be the result of spontaneous, long-term development. The opposite of self-generation, though stimulated, is the creation of an artificial area for the purpose of mobilising the local potential for development. The recovery of urban areas, once industrialized, is a third possible scenario.

After the boom years of the technopolitan phenomenon and the high expectations that accompanied it, in the '90s behavioural and structural actors will regulate the selection of the technopolitan species that have appeared, and have as their primary references urban and regional development, large company changes and the management of resources for training and research.

One must now wonder whether there will be more "assonance" or "dissonance" between the technopolitan environments and urban and regional development. Promoters of territorial development centred around the endogenous potential assign *smart* infrastructures (intelligent infrastructures built using the "bricks of knowledge" instead of the usual cement and clay ones) the role of stimulants and distributors of growth. A role, they claim, intrinsic to these environments since they are typically *smart* infrastructures. But this does not mean that they are capable of playing such a role. Actually, on initiative that appears as an enclave within the territory arouses predator-type behaviours, thus depriving the surrounding economy of its development potential, rather than producing the positive effects that renovation would bring about. It has been observed that such cases are anything but infrequent (Formica, 1991; Gibson, 1992).

Assonance between territorial development and technopolitan environment will instead be produced should the latter be designed as a network,

full of intersection points, cross-ways, multiple-direction flows, direct links among the small centres. The network technopolis acts in a global, enveloping way, developing *with* and not *against* its territory.

From this standpoint, a public authority intending to reproduce a number of locked technological fortresses, that some will wish to defend and others destroy, that generate sterile local rivalries, would meet with failure. On the other hand, possible results could be obtained from a public intervention encouraging the creation of technopolitan networks made up of a few, significant (international in scope) *smart* infrastructures.

The "open", variable geometry company continually changes shape. It enters a network with others, pushing markets and technologies to weave increasingly frequent multiple ties on a world-wide scale. It thus gives rise to alliances, even informal and polygamous, with its own competitors, because it is better to expand the market than to battle to gain shares of a flat market from one's rivals. It is both local and global, bypassing the national dimension. It is a system for learning, an organization for innovation that does not make it possible to erect hierarchical pyramids, but if anything knocks down those already built, having as its aim the continuous improvement of products, processes and services. To do so, it co-operates with universities and research centres.

It is easy to deduce that the technopolitan environment may be favourable, since it provides an international projection for local companies involved and offers support to foreign companies, taking advantage of the long wave of foreign investments that grow at a higher rate than international trade.

It is just as important for the prevailing aptitude of the technopolis entrepreneur to be not that of the estate agent, who cuts land into lots and raises buildings, but rather that of the artificial designer who first of all prepares the terrain most favourable to immaterial investments: those who create interaction between open companies, professional training and advanced research centres; who create activities combining company men, professors and researchers.

In this complex system, the technopolitan environment is not what appears from its individual actors. For example, it is not a university, nor a research centre. These resources are administered to produce synergy among subjects (businesses, training centres and study organisms) which interact in a complicated way. In short, there is a trade-off between using them to create and manage liaison structures between the educational and research systems and

the production system, and instead using them to encourage access to technopolitan environments by inward-looking training and research centres.

These are initiatives that require a long gestation period (even more than ten years) and a high density of investment.

a) Industrial liaison and technology transfer centres. The "industrial liaison" is the most highly-evolved and complex among the university-industry co-operation models indicated.

It mobilizes both immaterial resources (reflected, for example, in expenditures for personnel, technology transfer, services, marketing) and material (investments in real estate and miscellaneous equipment).

Its typical structure is the *liaison*, which puts the world of academic research and instruction into contact with the industrial world, and *technology transfer centre*, which acts as an agent to transfer technological knowledge and information.

Liaison and technology transfer activities generate co-operative processes between the resources of *talent, know-how, technology* and *capital* available in the university and industrial environments involved. Co-operation, in turn, adds "entrepreneurial value" to the resources themselves. For example, talent leads to the recognition of market opportunities, and is transformed into entrepreneurial skill to take advantage of them. *Know-how* appears as the ability to find and use skills in a variety of scientific disciplines, in order to translate technological innovations into marketable products. *Technology* produces specific technologies with a real market potential within a reasonable time lapse. Finally, *capital* promotes innovative entrepreneurial activities.

In Britain and the U.S., in particular, such Centres have a university matrix. The university prepares a liaison programme managed by the Centre, which markets academic research skills as a means for achieving technological goals, to the advantage of companies, who receive information, training, consulting services and research from the Centre.

The most successful co-operation is born out of high-quality research which, in turn, is the result of excellent teaching programmes.

Some Centres also have entrepreneurial training programmes aimed at the best students, who demonstrate a vocation for risk-taking. New companies often result from projects originating from experimental university theses.

The Centre may also not descend directly from a university, but originate instead from a local public intervention policy with the task of working simultaneously for various educational institutions (such as in the case of the liaison

programme of the city of Manchester, U.K.). Different forms of public-private partnerships may also be configured, as in the case of one of the first industrial liaison centres in Italy, developed at the Technology Pole in Piacenza from an initiative taken up by local authorities, trade associations, some businesses (not just local), and research organisations, flanked by several universities.

b) Entrepreneurial incubators. The incubator is a physical structure (with flexible spaces adaptable according to user needs) as well as organizational (with consulting and support services, including those to help find sources of financing) which welcome companies in the gestation period, those born premature, new-born companies (*start-up*) and small operative companies undergoing a transformation period.

Once the development stage which has been reached allows them to face the market freely, the companies raised in the incubator abandon this structure to settle in areas more suitable to hosting the production activity thus generated. Companies are hosted for a period of two to five years, generally speaking.

A team is charged with managing and assisting the companies present. The incubator is connected to universities and research centres, though this link may not necessarily be formal.

There are various types of incubators: generic (to host any type of company), those specializing in micro- or macrosectors or in technological branches (high tech).

It is interesting to observe that the latter are credited with greater chances for success and a higher growth potential with respect to generic incubators. Failures may be attributed to errors in estimating the potential market, contradictory and conflicting objectives or monoculture protection given to companies.

c) Business and Innovation Centres. The BIC is an enterprise that performs a number of functions to develop new businesses and innovation: selection and training of entrepreneurs, assistance in starting up new businesses, technology acquisition and transfer, financial assistance.

It is a creative environment, a production site (mainly intellectual: R&D, design and prototype development), and a meeting place, not only professional but social: an environment suited to considerably reducing the failure rate of the initiatives begun.

Through the BIC it is possible to accelerate and directly improve the process of *business creation*, and indirectly that of *job creation*, thus raising both entrepreneurial and employment levels.

Since the early '80s the EEC has conceived and launched a programme which, through the Business and Innovation Centres, promotes a rising rate of new business start-ups in EEC countries, especially in critical and disadvantaged areas, while at the same time reducing the mortality rate of the new business initiatives: the goal is to fall to approximately 20% of "infant deaths", versus the current estimate of 80% for new initiatives not "protected" by a Centre.

If, as the EEC model plans for, a Centre creates fifteen companies a year with a success rate of 80%, by the time the twelve surviving companies have become adult, and estimating an average of forty employees each, they will have generated 480 jobs, in addition to those produced indirectly. Finally, if the direct employment coefficient is high (it is assumed to be around 10), the annual activity of a Centre will generate approximately 5,000 jobs over time. This is the result of the lower early failure rate and the higher growth potential of companies started up by the Centre.

The Centre welcomes companies just starting up, those born prematurely, new-borns and existing small-sized companies which are developing diversification initiatives and making technological-organizational changes.

The reference technologies for the Centre are not necessarily the very latest; indeed, the interest in developing intermediate technologies within the small-sized companies at the Centre is high.

d) Science parks. First, we must distinguish "*first generation*" Science Parks from the "*second generation*". The first generation science park is an area that groups together various research activities (such as the American parks of the '50s and '60s).

The scientific research activities are situated within an urban-construction operation. Here, the process governing the appearance of innovations and the birth of new businesses is entirely random. These results should be produced by a naturally favourable environment, thanks to the contacts that interweave within an area having a high concentration of scientists, researchers, designers and students (Formica, 1991).

From the American experience, we can observe that the Park is often located on the grounds of a technological university that also acts as an estate agent. The university prepares an industrial liaison programme managed by a special structure (the Industrial Liaison Centre).

The park is populated by teaching and research organisms (institutional phase), large national and international groups attracted by the research potential and the quality of human capital available (first business stage), new

companies generated by ideas or projects within the large-sized companies present in the Park (second business stage).

The research park tends to promote activities at the technological sharp end. The accent is on the research portion of R&D, and the Park moves towards the third-level area (discovery), characterized by the high scientific contribution necessary and by the long time interval required in order to achieve positive economic feedback. From this point of view, it appears as a bridge between the end of the path of a mature technology and the beginning of another for a new technology (Perrin, 1989, Gibb, 1985; Henneberry, 1984; Kormetsky and Raymond, 1990).

With respect to the agglomeration-park, in the second-generation science park the emphasis shifts from scientific research (*development of knowledge*) to technological research (*development of applications*).

The aim is to encourage entrepreneurial spirit, and promote the creation of innovative companies. The creation process is not random, but carefully planned.

In order to systematically encourage innovative entrepreneurial spirit, the Park is equipped with an incubator (Rogers, 1986; Chanaron, Perrin and Ruffieux, 1987).

The park may also be a cabled area that takes advantage of new telecommunications technologies to connect operators, thus avoiding a strong commitment to the physical infrastructures of a limited territory.

e) Technological poles. A technological pole is the concentration, in a given field of technology (for instance, new production technologies), of skills and means having a national or even international scope, equally capable of ensuring synergy at the regional/local level with the economic fabric upstream and downstream, by carrying out activities that stimulate technology transfer (Saxenian, 1985).

The pole produces a cluster effect among businesses very active along the research-production-marketing line of high-technology products/services. In conditions of high and increasing environmental hostility, meaning high and increasing competitive pressure, the growing aggressiveness of world-wide competitors towards previously-neglected market niches, ever-more-numerous "invaders" from various industrial sectors, companies with few mutual connection points and those in areas with a low degree of functional integration of the territory (pre-cluster situation) are at a disadvantage. The purpose of the pole is to act as an evolutionary space for the formation of industrial clusters, until the critical mass of inter-company links is achieved. In this

way, the pole helps strengthen the competitiveness of companies in turbulent markets (Formica, 1991).

The Technological Pole is created from a nucleus of companies belonging to the same technological and geographical sphere, which initially share a situation of "neutral coexistence", that is characterized by a few points of intercompany contact and the absence of a territorial value chain. In this situation, local know-how and technological, entrepreneurial, professional, training, and financing resources are only partially utilized, with negative effects on their growth rate. Under the thrust exerted by at least one of these companies, which is generally and mainly the leading company among them, "neutral coexistence" gives way to an "interventionist" policy, thus starting the value chain. Thus there is a shift from the disaggregated area to the area of evolution where the first company aggregation acts as a pole of attraction for other companies, both indigenous and extraneous, as well as universities, research centres, consulting firms, etc.

In the technological pole, high-technology settlements cohabit with manufacturing firms and others dedicated to intellectual production. In the final stage of enhancement, the area in evolution may take on the configuration of a technopolis, of which the technological pole will become a component.

3.6. TECHNOPOLITAN EXPERIENCES IN THE UNITED STATES AND JAPAN

In the '80s, the world-wide explosion of the technopolis phenomenon took place within an international context of accentuated diversity of macroenvironmental problems experienced first-hand by the leading economies of the western world, and transmitted from them to their satellite economies. The process of creating technopolitan habitats was significantly influenced by this, though each responded to the specific needs of the local economy in question.

In the case of the United States, the macroenvironmental problems rotate around the technological challenge of Japan, in a macroeconomic system conditioned by "twin" deficits (public debts and foreign debts). For the Japanese, the testing ground is their ability to develop creativity, gain recognition as pioneers of innovation. To be the first by employing the utmost effort has become the Japanese innovation strategy that has gradually surpassed the more traditional path of "creative imitation". Finally, the EEC continues to deal with employment problems, mature industries to be inno-

vated, co-operation within the community which is still weak, though stimulated by the institutional perspective of the unique European market.

a) United States

The various experiences have at least three strong points in common. Specifically:

- The university–research–industry synergy earlier encouraged by federal policy towards research in military-industrial fields, and also sustained by the policy of the large foreign companies, especially Japanese, which settle in American scientific parks and technology complexes, participating in joint university-industry programmes promoted by prestigious centres of higher technological education, such as MIT in the Boston area.
- Mobilization of new entrepreneurship in the area of risk capital, which provides "financial oxygen" to new high-technology businesses.
- A new concept of "enterprise spirit", which rewards the creation and development of organizations capable of experimentation as opposed to those maintaining the strict, bureaucratic structures that arose in the '50s with the "company man" model.

These also have two tendencies in common, which have come about during this decade. The first consists of leaving the isolation in which each activity lives in the local economy, participating in creating a network of initiatives that mutually support one another. The second trend is increased public-private partnership, both in activities in progress and in the initiatives to be started up. Typical experiences are related to:

- grouping together high-technology industries, the high technology context;
- science parks;
- incubators for new companies.

The former are "spontaneous" technopolis areas: agglomerations of high-technology companies, even manufacturing, and research centres created over several decades, with risk capital provided by venture capital firms.

Their formation was encouraged by the presence of technological universities nearby (Stanford University and its research park in Silicon Valley), as well as by a long-standing financial tradition combined with close and just as long-standing relations between university and industry (as in the case of the "route 128" technology complex in Boston). Other experiences are Minneapolis–St. Paul (Minnesota), Silicon Prairie (Texas), Greater Ann Arbor (Michigan), Pittsburgh (Pennsylvania), Washington–Baltimore, Metrotech

(New York State), where thausands jobs have been created for researchers and scientists.

The science parks gather around the universities or are located on their grounds (in which case the university acts also — or only — as estate agent). Parks have also been promoted by local communities, as well as by the universities themselves.

The typical American park is a comfortable working environment, with highly qualified human resources, an important technological university, advanced research structures, financial institutions that promote risk capital. Especially significant is the system of relationships and consulting that link the university to industry. The university in the park manages an industrial liaison programme through an internal structure (liaison office or structure) which markets the research skills of the university, satisfies the specific needs of each industrial client, and the most appropriate professor-experts look after user problems.

American experiences with scientific parks began over thirty years ago: the first one, the famous Stanford Research Park, linked to Stanford University in California, was created in 1951. Their golden era was in the first half of the 1960s, when numerous initiatives were launched. In subsequent years, interest dropped off considerably, to rise again in the late '70s. An examination of successful and unsuccessful experiences makes it possible to identify the critical location factors: scientific structures and infrastructures, management centres, an organized urban environment, an innovation-oriented environment, possibility for professional and cultural relationships, high quality skills, public services, availability of venture capital, market and distribution network, connections with residential areas.

The most important motivations are: functional needs; contiguity with the research market; shared facilities; exchange experiences; co-operation on programmes; vicinity to political, economic and financial establishments; vicinity to clients and thus financing; stimulation to apply scientific results; appreciation of entrepreneurial aptitude in scientific personnel; need to acquire stimulation for one's research and compare notes with scientists in other disciplines; search for quality of life; to avoid long-distance commuting; to enjoy an environment rich with points of interest; to avoid problems in personnel recruitment; availability of risk capital; easy customer contact.

The Advanced Technology Development Centre (ATDC) is related to the prestigious Georgia Institute of Technology. It was created in 1980, and in 1984 hosted twelve high-technology companies, and planned expansion to

accept seventy firms. The initial cost of the project was around 1.4 million dollars.

The University City Science Centre (UCSC) in Philadelphia was founded in the late '60s with the aim of revitalizing an especially depressed area of the city. A science park has developed together with the Centre.

The American experiences highlight various factors for success of the incubators: flexible use of space; promotional activity; managerial experience of the directors; ability to assess potential new business owners; ability to attract risk capital; combination of new and already-successful businesses; clear, straightforward leasing contracts; interaction among participants; technical assistance rates aligned to tenants' spending capacity.

One major qualifying aspect is their ability to promote the search for financial sources and mobilize considerable risk capital.

b) Japan

A deliberate intervention policy by the central government, the involvement of local authorities (especially provinces) and the mobilization of the media characterise technopolis projects. These respond to a development logic aimed at promoting a society founded upon science and technology, in place of one aimed at mass industrial production.

The Technopolis idea matured in the early '80s within Miti (the Ministry for International Trade and Industry), and was developed by an internal consulting committee (the industrial structures council).

The problem is how to launch a new territorial layout policy through local planning, in concert with the central authorities, to create new regional poles of development. The desire is to avoid repeating the mistakes of past forced-relocation experiences in unsuitable contexts (according to some experts, this is the case of the pioneering Tsukuba technopolis).

Thus priority is given to areas near "mother cities", well-equipped from an infrastructural point of view, and which also offer high-level research centres.

In the beginning, each area has a pair of technological vocations corresponding to its traditions and resources: this means taking advantage of the endogenous potential of the area. Productions with a high added value and low transportation costs are to be encouraged at all times. In 1983, a national law was passed for the technopolis creation programme. Each project must comply with the following requirements:

- Presence of three interacting components: industrial and distribution companies and other commercial structures; universities and public R&D institutes; a residential area hosting scientists, researchers, professors, business executives and their families.
- Proximity to a "mother city" with a minimum of 200,000 inhabitants.
- Location within a rapid transportation network, for connections to the large cities Tokyo, Osaka and Nagoya, with return trips possible in a single day.

Twenty areas were selected according to these criteria as candidates for the role of technopolis.

Since Miti intends to stimulate competition between these technopolis areas, competitive tension will lead to a second selection stage some time in the '90s.

The cost of a technopolis was estimated in the early '80s at around 600 billion yen. For such a large investment, the authorities moved to find funding from abroad as well, from United States investors. At the same time, they tried to launch joint ventures between public and private operators.

The technopolitan programme is also supported by a series of related activities. Thus an association has been formed that brings together the managers of technopolis projects, industrial environment and Miti executives six times a year. The latter act as "migrating birds", periodically transferring their skills from the ministry to private businesses, where they are employed in roles of responsibility, and the organizational structures of the technopolis areas. Furthermore, Technopolis Lease has been created, whose participants include Miti, the Japan Development Bank, and large companies such as the Mitsui Co. and the Mitsubishi Corporation, with the task of encouraging investment in leasing by private parties to stimulate location. Finally, a market computer network will link all technopolis areas and promote the international transfer of technologies.

Not all Japanese experiences may be traced back to the technopolis. Spontaneous aggregations exist in Japan as well, such as Mechatronics Valley, within the powerful Nagoya automobile industry, hosting the most important Japanese technological innovation centre for mechanics, electronics and robotics.

3.7. CASE STUDIES OF INCUBATOR EXPERIENCES

A) The Berlin Business and Innovation Centre (BIG)

The Berlin centre for innovation and new businesses was created in 1983 as an initiative of the Berlin Technical University and the Senate for Economic Affairs (Fiedler, 1985).

The centre is managed by the University itself through the *Technology Transfer Unit*, in co-operation with the Senate for Economic Affairs. The University has been co-operating with industry for many years, to flank the technological research experience acquired by the University with the needs of new innovative companies, aimed at developing and selling new products.

Co-operation programmes have been set up, such as employing University graduates at SMB and organizing SMB executive training seminars in high technology fields and marketing. Some university departments have been set up within BIG, including:

- Institute of mechanical engineering.
- Institute for the development of bionics and technological standard measurement.
- Institute of chemical engineering.
- Institute of applied geophysics.
- Institute of civil engineering.

The support provided to businesses consists of offering the needed space near research institutions, and a series of services to help companies during their early growth stages.

Approximately 5,000 square metres are set aside for incubator use: these are rooms whose size may be adapted as needed, by means of partitions, where companies can take advantage of technical and consulting services. In addition to technical assistance from research institutions, common administrative assistance services are also provided, such as: consulting on accounting, marketing, business planning, secretarial services, telex, telefax, conference rooms.

The Technology Transfer Unit plays an active role, as a university service, run under direct control of the University rector.

The Senate for Economy has developed business financing programmes,

not for use solely by those hosted by BIG; the financial instrument is the Innovation Fund, created in 1982 with public funding.

An initial subsidy is available (40% of salary) to companies who hire university graduates or who accept students as interns.

Various venture capital activities have been operating for several years, offering share capital and managerial assistance.

Near the BIG stands the complex of buildings hosting the Technology and Innovation Park, which represents the evolution of BIG itself.

Of its 80,500 square metres of indoor space:
- 30,000 are used by university research institutes.
- 45,000 are set aside to host companies.
- 5,000 are occupied by the incubator.
- 500 hold the service centre

The main areas of study are:
- Civil engineering and new materials.
- New technologies in transportation.
- Environmental technologies.
- New sources of energy.
- Computer science.
- Medical technologies.

The considerable amount of space available has encouraged rapid settlement by companies; the most highly represented sectors are electronics (components, measuring instruments, computers) and energy.

The financial resources necessary in creating the centre were provided by the Senate for economy and transportation (70%) and the EEC (30%).

B) Aston Science Park: a second-generation science park

This stands near the University of Aston, near Birmingham, Great Britain.

It was created in 1983 as an initiative of the University of Aston and, in particular, its vice-Chancellor, Sir Frederick Crawford (Nicholls, 1985).

Three stages of development were planned: the first extending the surface area by approximately 25,000 square meters; the second, building nine new buildings of approximately 1,500 square meters each; and the third plans to purchase an additional area of approximately 9,000 square meters.

The City of Birmingham and the University of Aston created a partnership to manage the park: Birmingham Technology Ltd. (BTL).

Lloyds Bank also entered the enterprise, by contributing along with the city of Birmingham to the creation of a venture capital fund, managed directly by the BTL.

The selection to admit new businesses into the park is handled by a committee (University Science Park Liaison Committee), made up of eight professors chosen from among the four University departments involved.

The committee also acts as liaison between the university and industry.

The assistance provided in creating new companies rotates around four categories of services:

- Joint and individual conventional services.
- Technical consulting.
- Financial services.
- Services provided by the university.

Chapter 4

THE DYNAMICS OF PRODUCTION TECHNOLOGIES AND STRUCTURES

4.1. THE NEW NEEDS OF SOCIETY

In relation to the new paradigms related to sustainable development, the new needs of society are: natural resources and environmental balances conservation, health and safety improvement, hunger defeat, unemployment reduction, quality of life improvement, economic distance between developed and developing countries reduction. All of these needs have started a new revolution in devising and developing the industrial activities and in consumption patterns.

In relation to the economic changes that have occurred since 1975, companies involved in mass, standardized production are changing their production structure according to the new parameters of elasticity, flexibility and cost effectiveness (Balzarini, 1986). The plant and organization solutions typically adopted in a rigid production structure, unable to adapt to the increasing segmentation of markets without losing productivity and raising costs, due to the long time necessary in order to set up lines to change product type. Rigid processes use highly specialized plants, which make any adjustment aimed at creating operative flexibility costly, due to the close interdependency between the product and the process by which it is obtained.

The thrust towards greater production variety and variability is thus increasingly imposed by external factors; but internal factors make it possible. External factors lie in the market: the consumer demands an increasingly wide range of products from which to select.

Internal factors lie in the production area: new technological methods and inventions make it possible to satisfy consumer demands. Production managers return to a front-stage role, occupied for decades by marketing. They have the task of introducing "real variety" into the production output, as opposed to the "apparent variety" created by the marketing function.

When the consumer began to demand a certain variety of products, production structures proved themselves to be technologically incapable of

generating a real variety of output. This led to the success of marketing, aimed at providing the consumer with an apparent variety: where routine (and thus excluded from top-level management) production choices ended, marketing choices began, whose power base within the company extended to the point of involving the decision-making process of top management.

Initially, the functions of marketing were especially effective, since the variety of production was minimal: each business focused on some exclusive property of its products, and the consumer could compare these attributes with those of other brands. The difference was based on subtle details, such as the brand name, the package, the association of image: it was therefore "apparent".

Currently, the consumer is no longer satisfied with an apparent variety, but demands instead the possibility of choosing from a real variety of output. Since only the production function has the (technological) ability to create a real variety of output, its role is destined to become a priority once again. Production is thus called upon to discover and apply the means with which to offer a sequence of articles, each of which is markedly different from the previous ones. This is made possible by the application of new design/planning technologies and modular production.

The new product design technologies make the features of the finished product independent from those of the plant used to obtain it. That is to say, they make it possible to design a catalogue of parts that can be combined in different ways to create a series of finished products. The production range is thus no longer conceived as a set of distinct articles, but rather as a set of parts interchangeable among the various models in the range (Goldhar and Jelinek, 1984).

4.2. CLEANER PRODUCTION TECHNOLOGIES

For sustainable development to be achieved, new production patterns are needed which will result in lower environmental loads and improved industrial performance.

Cleaner production has been widely recognized as the best way to sustainable development.

The cleaner production concept may be defined as "the continuous application of an integrated preventive environmental strategy to processes and products to reduce risks to humans and the environment".

For production processes, cleaner production includes conserving raw materials and energy (through a reduction of material and energy intensities), eliminating toxic raw materials, and reducing the quantity and the toxicity of all emissions and wastes before they leave a process.

For products, the strategy focuses on designing for recyclability, using renewable materials and extending product service life; in other words, the final aim should consist of increasing the overall function delivered by a unit amount of natural resources.

The main principles which the cleaner production approach relies on are examined hereafter.

The *precautionary principle* drives a reduced release into the environment of toxic or hazardous substances, especially when there is reason to assume that damage or harmful effects are likely to be caused. As a result of that principle, anthropogenic inputs into the environment of unnatural substances (or of natural substances in very large quantities) should, as a general rule, be avoided (Dethlefsen et al., 1993), and this requires a basic change in present production systems which notably generate high material flows to the environment.

The precautionary principle is, somehow, closely related to the *prevention principle*. Prevention, indeed, may be realized through lower or no emissions into the environment in order to avoid negative effects. Even the more traditional end-of-pipe approach prevents pollutant releases into specific environmental media, but, by simply shifting a particular contaminant from one medium to another, it does not focus on the earliest cause of environmental damage, that is the processes generating pollution.

Therefore, a preventive approach should emphasize on changes upstream in the production systems, reducing the creation of potentially polluting emissions and, thereby, the risk of environmental damage at the source. This upstream perception of existing connections between economies and the environment entails reconsidering product design and consumption patterns, and, therefore, the whole basis of economies.

Another primary principle of cleaner production is the *integration* of environmental protection actions across various systems. It should be realized, indeed, that selective actions do not always induce a generalized environmental improvement, and displacements of negative effects may even arise. For instance, since a preventive approach focuses on disruptions caused by production processes, environmental burdens related to product utilization and/or consumption may be overlooked; or a reduction of emissions in one

industry may not lead to an overall reduction of emissions. Such situations can be avoided by ensuring that clean production follows an integrative approach, through the consideration of all the material flows from/to all environmental media over the whole life-cycle of a product (Jackson, 1993).

Cleaner production is mainly realized through, on the one hand, the achievement of higher material efficiency levels, and, on the other hand, the minimization of toxic and hazardous substances released into the environment (Roustan et al., 1996).

A higher material efficiency of the overall economy entails the lowering of materials and energy resources required per unit of function delivered. It is significant to stress that a better material efficiency also results in improved economic efficiency, as, at company level, material savings per output unit correspond to decreasing unit costs.

Material efficiency may be raised through different options: redesigning less energy- and material-intensive processes, upgrading, reusing and repairing products, or recycling their material content, modifying consumption patterns towards a higher product utilization rate and durability (Clift and Longley, 1995).

In a wider sense an increase in material efficiency means reducing the material requirement for meeting any given need from the population.

It must be highlighted that the simple adoption/development of more material- and energy-efficient technologies in production processes cannot ensure the achievement of sustainable development, mainly because of thermodynamic limits; therefore, the cleaner production concept should also include — as already stated — the implementation of new "re-producing" criteria which are typical of "closed-cycle economic systems" — in place of the traditional "producing" criteria, typical of "open-cycle economic systems"; this means the diffusion of the practice of reconditioning, repair, reuse, recycling, development/upgrading.

This great transformation cannot be easily and economically made, unless goods are no longer produced and utilized the same way they have been up to now: a profound change is needed in the design of durable goods, in such a way as to enable their further development/upgrading by replacing specific parts, instead of the whole product (as it can be done for, e.g., computers and aircraft). These practices, all together, will contribute to reduce the intensity of materials and energy flows in the economy.

Some different cleaner production technologies can be developed and implemented, with different features and effects: from fairly sophisticated

TABLE 4.1. Some successful case studies of cleaner production in the world

Type of activity	Fermentation	Pine apple processing	Polyester production
Company	Fuyang General Distillery China	Del Monte Philippines INC The Philippines	PT TIFICO Indonesia
Features of the cleaner production	a) special training b) periodic maintenance of equipment c) control of washing water to reduce wastewater d) reuse of cooling water e) obtaining guarantees of raw materials f) improving raw materials storage	Minimization of wastes Reduction of environmental risks Improved process efficiency	programme of closed loop cycle of the whole process
Advantages	Reduction in wastes (grain and water) Reduction in water and energy consumption Simpler production and management	juice savings amounting to more than 55 litres an hour improving safety conditions of work	a) Re-use of solid waste b) natural gas utilization c) industrial water recycling d) Exhaust gas recovery
Cost savings	874,000 RMB per year	US $ 48,000 per year	a) US $ 7,020 per year b) US $ 387,000 per year c) US $ 53,408 per year d) US $ 601,843 per year
Capital investment	1,097,000 RMB	US $ 17,800	a) none b) US $ 673,700 c) US $ 12,074 d) US $ 1,105,990
Pay-back period	< 1.5 years	9 months	a) immediate b) 1.7 years c) 3 months d) 1.84 years

Source: UNEP, Industry and Environment, Special Issues on Cleaner Production, 1994 and 1995.

TABLE 4.1. Some successful case studies of cleaner production in the world (*continued*)

Type of activity	Textile dyeing	Panelbeater's repair shop	Textile dyeing
Company	Australian Dyeing Company Australia	Barry Mansfield Smash Repairs Ltd. New Zealand	Quìmica y Textiles Proquindus SACI Chile
Features of the cleaner production	Process innovation aiming at: a) environmental protection; b) improving quality production	Process improvement aiming at : a) reducing pollution b) reducing material use and waste	Assessment of the different pollution prevention opportunities, therefore analysis of the production process
Advantages	a) cost is comparable with traditional dyeing but the quality is improved b) the Company's image has improved as a result of the superior product	Reduced levels of air pollution Savings on the purchase of materials Improved working conditions Healthier work place Increased business from large car owners as a result of a tidier, cleaner workshop	Improvement in operating efficiency and product quality Reduction in toxic levels of wastes Savings on raw materials usage Demonstration of economic and environmental value of cleaner technology in this industry
Cost savings	A$ 619,200 per year	a) due to new paint spraying system NZ $ 7,500 b) due to other additional savings in the process about NZ$ 3,000 per year	a) replace sulphate with sodium chloride $ 7,500 per year b) modify rinsing procedures $ 45,000 per year c) filter sulphuric acid continuosly
Capital investment	A$ 400,000	a) NZ$ 2,400	a) none b) $400 c) $700
Pay-back period	8 months	a) 4 months	a) immediate b) < 1 week c) 2.5 years

technologies, which increase all aspects of global efficiency (including material, energy and environmental efficiency), reduce production costs and increase competitiveness of the adopting company, to fairly simple technologies which only improve the environmental efficiency.

The different types of cleaner technology can be advantageously implemented by companies as a consequence of internal and external factors.

Internal factors include: nature of the company's industrial process, size and structure of the company, attitudes affecting operations of the company, available assets and information, willingness to take risks, attention to environmental and resource concerns, *lack of information about technological evolution.*

Small- and medium-sized enterprises (SMEs) contribute a significant negative environmental impact, especially on a cumulative basis. A widespread adoption of cleaner technologies by smaller companies is, therefore, beneficial. It is, however, difficult for these companies, which are more vulnerable to risk than larger ones, to afford meeting the costs related to improvements in environmental performance and, at the same time, to be competitive on the market (Lin, 1996).

However, SMEs are more flexible in their ability to innovate and change their production systems and products. Thus, in relation to the cleaner technology concept, the size and flexibility of SMEs may be more suited to changes in management practice than larger and more culturally rigid organizations.

Despite this higher flexibility and the attractiveness of long-term profitability, some barriers — the lack of resources and information, as well as the short-term pressures of survival — may hinder the adoption of cleaner technologies in SMEs.

Several initiatives have been promoted by UNEP in the last few years, in many countries and different industrial activities, and have given positive results, both environmentally and economically. Some of them are summarized in Table 4.1 (taken from special issues of *Industry and Environment*, 1994 and 1995).

4.3. MODULAR PRODUCTION

The basic idea of this type of production consists of having a set of parts that can lead to various, interesting production configurations. Basically,

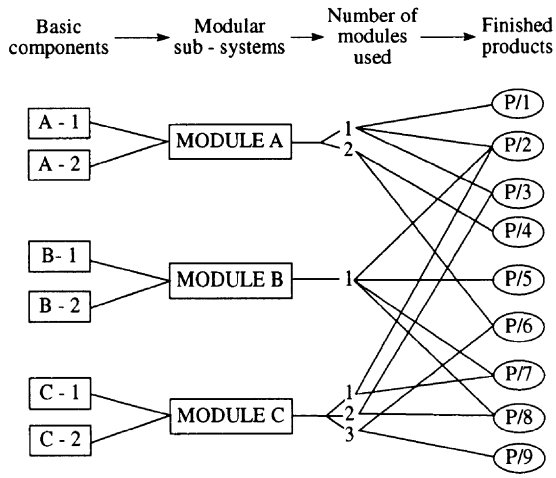

Figure 4.1. Basic features of modular production

each order received by the company is translated into a single assembly arrangement.

It is obvious, then, that the effectiveness of such a system may be "measured" on the basis of the number of products that may be generated by a certain number of parts.

Figure 4.1 clearly shows the progressive and various assembly procedure that characterizes modular production. If, then, the methods and sequences with which the parts can be combined also increase the variety, the number of possibilities is even higher.

Obviously, many of the theoretical possibilities are impossible, as they would have no attraction for the consumer.

Production and product construction using modular criteria is an initial answer to the demand for flexibility, elasticity and containing production costs.

Flexibility is increased by modular production, since the speed and ease of production changes are ensured by the interchangeability and many possible combinations of the modular parts within the product range.

Flexibility is greater, since the "modular" features of the sub-systems make it possible to convey parts towards those products which are most in demand on the market at a given time.

Finally, modular production contains production costs, since modular technology reduces a high number of finished products to a more limited set of basic parts, sub-groups and groups of components, with positive effects

on machinery set up times, materials movement, production scheduling and stock control.

In order to create a system of modular products, both a technical-functional analysis and rationalization of the process are necessary:

– the technical-functional analysis is aimed at ascertaining the product features that best reflect market needs, defining the technological priorities of the parts and materials to be used, identifying a structure for the single product and range of products that is functional from the standpoint of both technical and market needs;

– process rationalization (production of basic parts, sub-systems of parts and finished products) is aimed, on the one hand, at standardizing and homogenizing all joining elements (screw diameters, container sizes, thicknesses and diameters for interlocking parts), so as to satisfy a countless number of needs using only a few, pre-set values among the infinite ones that may be assumed by a variable; on the other, at classifying each manufactured part, at any stage of the process, in a "family" determined according to the morphological, technical and functional features of the parts. All of this serves to incorporate modular planning-production into a production system by manufacturing cells (group technology), capable in turn of conciliating the need for productivity with the need for flexibility. In order to better understand the change in product design philosophy, it is useful to refer to a real example, that of the "automobile" product. The standardization of the basic parts of a product and differentiating models by combining different component parts has recently been applied to an interesting version in the FIAT car range: some models use complex parts (propulsion units, transmission systems, some chassis and body elements, lighting group) common to many products in the range.

The most obvious example is the F.I.R.E. engine (designed using CAD technology), mounted as a standardized component on various models.

Finally, we shall recall that the development of the "component industry" falls within this evolution of car product design philosophy (Conca, 1986): on the one hand, we see an increasing standardization of components that do not contribute to differentiating products; while on the other, there is considerable differentiation among the "visible" components — however, while standardizing and homogenizing interfaces for connection, and thus assembly on other models as well.

4.4. GROUP TECHNOLOGY AND CELL PRODUCTION

Department production satisfies the need for operative flexibility, but it is a low-efficiency solution. Vice-versa, line production is highly efficient but rather rigid. There are solutions, such as the arrangement of departments in line or the use of detached lines, that allow intermediate levels of productivity and flexibility. Recently, a type of layout based on "manufacturing cells" has been successful, again offering intermediate levels of productivity and flexibility. The importance of this layout lies in the fact that it may be associated with a particular production philosophy, group technology, and a group-oriented organization of labour. Overall, a new production system is thus created, characterized by a production philosophy in which similar components are grouped together in "families", a layout in which machinery is organized in small groups (each of which handles a single family of components) and based on the principle of group work.

This system has laid the foundations for introducing flexible automation, which requires a fragmented process.

Group technology is not the result of the traditional break up of the process, but rather dismembering the product into its various component parts, each of which corresponds to a particular, complex stage of the production cycle.

Similar components are identified and classified into "families" for the purpose of organizing a more efficient production and design system. Productive efficiency is increased by organising the plant into groups of machines (cells) so as to facilitate the flow of parts being processed.

In the producing design, efficiency is increased by classifying and coding component parts, that is identifying the similarities between parts and relating them to a coding system (Groover, 1987). There may be two types of similarities among parts, depending on whether they concern:

- design features, such as geometric shape and size;
- production features, thus the sequence of steps necessary in order to produce the component.

A "family of components" may therefore be defined as a group of parts similar either in size and geometric shape or in the steps necessary to produce them.

Parts in the same family may be (and generally are) different from one another; what counts is their similarity in the aspect considered for classifying them within that family.

The most significant problem is the classification of parts: three methods may be used to solve it, having different levels of complexity and cost.

The first method is visual inspection. This consists of observing the physical parts (or photographs of them) and arranging them in groups based on their similarities. This is the least accurate system, but also the least expensive.

The second method is classification and coding based on the design and production characteristics.

This type of classification requires attributing a code number to uniquely identify the characteristics of the part. This is the most widely-used method today, but also the most complex and costly.

The third method is the production flow analysis, based on the sequence of operations rather than the design of the parts. Parts with identical or similar routing are grouped together in families. This method is less accurate than the previous one, but also less expensive.

The production of each specific "family" requires arranging the machines into cells.

The arrangement by cells is basically the result of combining product-flow layout and process layout, and is the solution towards which both strict continuous-process lines — no longer economically viable in current market and environmental situations — and complex functional layouts of intermittent processes — whose flexibility is no longer able to compensate for low productivity due to conversion costs and labour yield, are beginning to orient themselves.

In each cell we therefore find the machines (even with very different functions) necessary in order to produce a given family of components (manufacturing cell) or, in the case of assembly, necessary in order to assemble a complex stage of the production cycle ("assembly islands").

From this description, we understand how, from the standpoint of organizing work and managing activity (interchangeability of workers, possibility of group incentive programmes, short-term production scheduling methods, etc.), the "production cells" and "assembly islands" (the most complete and therefore correct terms) are similar in the end, while the motivations that lie at the base of these two production systems are different. For cells, the final aim is an attempt to gain the advantages of large series production even for small- and medium-sized series (although to the detriment of a certain plant flexibility); for islands, the basic reason is essentially an attempt to respond to the demand by workers to carry out more com-

plete and meaningful tasks, while also satisfying the needs dictated by the production philosophy that is gaining increasing recognition today: breaking down the product (rather than the process) and thus modular production.

Usually, machines cannot be divided completely into specialized cells; part of them must be grouped in a large, non-specialized cell, which is basically a job shop (Greene and Sadowski, 1985).

Some problems arise in applying group technology:

- it may be difficult to identify the families among the many components manufactured by a system.
- the cost of classifying and coding the parts may be too high;
- if several cycles must be carried out for several products, it may not be possible to divide the various cycles into technologically similar stages (this division is necessary in order to achieve volumes — by accumulating the flows — that ensure sufficient utilization and balancing levels of the cell capacity);
- a change in the manufacturing mix may cause an imbalance within the cell;
- a machine breakdown may block the activity of an entire cell;
- it may not be easy to identify the most appropriate machines to manufacture a given family of components (and thus the machines to be included in a certain cell);
- there may be a certain resistance within the company to changing to a new organizational form, such as group technology.

On the other hand, group technology offers consistent benefits in the following areas:

Product design – The benefits derive from adopting a system of classifying and coding parts. When a new part must be designed, its code may simply be compiled according to its features.

It is obvious that this saves time in designing a new part whose function is fully satisfied by pre-existing parts. In any case, even if there is no part that corresponds exactly to the required specifications, a slight change in an existing part may be sufficient in order to make it.

Equipment and set-ups – The equipment is standardized and capable of working any component in the family. The machine tools do not require radical set-ups, since the machined parts are similar. The set up times are thus very short, and it is easier to organize the sequence of processes to reduce the number of changeovers necessary.

Materials handling – The handling of working parts is greatly reduced; they circulate within the cell, at times following highly efficient flows, thus also reducing the waiting times for machining. In short, the efficiency of the process is improved, reducing production costs.

Production scheduling – Group technology simplifies production scheduling: in fact by grouping the machines into cells, the number of production centres to be scheduled is reduced. Even classifying the parts into families reduces the complexity of the problem. Due to the reduced set-up and more efficient movement, the production lead-time and work-in-process for each element are reduced. The reduction in these parameters may be as high as 50%.

Process planning – An appropriate classification and coding of parts makes it possible to create an automated process planning system. In any case, even without automating this process, time and money are saved in planning, thanks to standardization. The new parts are given a code that identifies the unique family to which they belong, and thus the general path of the production process is already determined.

Personnel organization – The advantages of group technology in this area are especially related to the greater autonomy of each worker and the expansion of his duties, shattering the assembly-line logic, reducing micro-conflicts and absenteeism and accentuating the flexibility of manufacturing jobs.

4.5. FLEXIBLE MANUFACTURING SYSTEMS

Flexible manufacturing system (FMS) may be defined as an integrated set, controlled by computers, made up of numerical control machines, automatic materials and tools handling equipment, automatic measuring and control systems which, with minimal manual intervention and low set-up times, can handle any type of product belonging to a specific family, accepting variations in the production capacity and job schedule within a certain range (Greenwood, 1988; Drozda, 1988; Maleki, 1991).

It is therefore a robotized system within which the computer controls not only the operating machines (lathes, drills, welders, assembly and painting complexes, etc.), but also the auxiliary equipment (systems to move and position parts) (Choobineh and Suri, 1986).

Recently designed FMS are conceived so as to completely automate the flow of materials; in these systems, the tool stock is automatically moved

from the preparation room to near the machine, where the tool changing device can automatically load them (Salomon and Biegel, 1985; Nelson, 1986; Gupta, 1988).

The equipment and machine used in an FMS depend on the type of work carried out by the system. In a system designed for mechanical machining operations, the main stations consist of CNC machine tools.

Some FMSs perform assembly operations, although the flexible automation of this activity makes up only a small part of all assembly complexes today. The most appropriate workstations in these applications are made up of industrial robots; these can be programmed to perform tasks in various sequences and using different specific techniques, in order to adapt to variations in the assembled models.

Track-free carriages electromagnetically guided along belts (Automated Guided Vehicles, AGV) make up the most recent solution to the significant problem of transporting parts; their success is linked to their extreme flexibility, which allows the parts to stop only at the necessary machines and makes it easy to change the system layout. This flexibility has extended use even to manual assembly lines (Hollier, 1987).

Various forms of flexibility may be achieved:

1) *Machine flexibility*: ease with which the machines within a system can be repositioned, in terms of tools, equipment, numerical control programs, etc., to tool parts belonging to the same family. The set-up time for a machine tool includes: tool preparation time; time to load, position and unload the part; time to replace the numerical control programme.

This flexibility may be achieved by using sophisticated devices to load tools and parts, by appropriately assigning operations to avoid tool changes or reduce the number of equipment changes, by gaining the technological ability to replace the part and the tool simultaneously.

2) *Process flexibility*: ability to manufacture groups of parts with different machine cycles, even when using different materials (this is also called "mix flexibility"). This type of flexibility is greater the lower the machinery set-up costs; in these conditions, each piece can be machined individually, rather than in batches. One measure of this flexibility may be the number of types of parts that can be machined simultaneously, without resorting to batches. This flexibility may be attained by achieving machine flexibility, by creating multiple-purpose and adaptable CNC machining centres.

3) *Product flexibility*: ability to produce a new set of products with limited changeover times and costs. It may be further specified as "piece flexibility" (addition and/or removal of pieces to production over time) and "design change flexibility" (timely execution of technical changes in the design of a particular piece). This flexibility may be measured based on the time required to change from one mix of parts to another, and may be achieved by using an efficient and automated manufacturing control and planning system and machine flexibility.

4) *Routing flexibility*: the ability of the system, in the event of unit breakdown, to continue working by having other units intervene, which thus also perform the functions of the blocked unit. This ability implies the possibility of machining a part in more than one sequence or, equivalently, the possibility of carrying out a given operation on more than one machine.

Routing flexibility may be "potential", thus usable only in the event of a machine breakdown (while ordinary sequences remain fixed), or "real", meaning that identical parts ordinarily follow different sequences, regardless of breakdown situations. This flexibility may be measured based on the "sturdiness" of the system in the event of a machine block: the production rate must not collapse and the parts must continue to be machined. This may be achieved: by creating an automated system to re-route the pieces (potential flexibility); by organizing the machines into groups (real flexibility); by duplicating the assignment of machine operations (real flexibility).

5) *Volume flexibility*: ability to produce various levels of output in remunerative conditions. A higher level of automation increases this type of flexibility, due to both the reduced set-up costs and variable costs, especially those for direct labour. An FMS may be aimed at alternative productions in the event of a fall in market demand, and may just as effectively deal with variable use of its production capacity. This flexibility may be measured based on the minimum volume that may be produced by a given part without jeopardizing the productivity of the system. The lower this volume, the more the system is quantitatively flexible. The flexibility of the volume may be achieved: by using multiple-purpose machines; by designing a non-dedicated layout; by creating a sophisticated automated system for material handling, having conveyors with flexible paths; by achieving routing flexibility.

6) *Expansion flexibility*: ability to expand the production capacity of a given system with ease and through modules. This cannot be done with the traditional continuous lines, which often require system duplication. This flexibility may be measured based on the maximum amplitude that may be achieved by the system, and can be attained: by designing a non-dedicated layout; by creating a flexible system for materials movement; by designing flexible (and modular) machining cells; by achieving routing flexibility.

7) *Operative flexibility*: ability to change the sequence of operations on each group of parts. Usually, when machining a certain type of part, there is a partial relationship of precedence among the various operations to be carried out; however, for some operations, the respective order is arbitrary. This flexibility may be increased during the design phase, by leaving various operative options open, thus without determining a set order for all operations. If operative flexibility exists, it is possible to decide in real time which operation to perform (and on which machine), based on the current status of the system (thus based on whether each machine tool is fully or partially in use, or unused). This obviously requires machine flexibility.

8) *Production flexibility*: set of groups of parts that a system can manufacture. This is achieved by increasing the technological level and versatility of the machinery; in short, all types of flexibility illustrated above are necessary.

Many of these types of flexibility are interdependent; in particular: machine flexibility is necessary in order to achieve process, product and operative flexibility; routing flexibility is necessary in order to achieve volume and expansion flexibility; all of the types listed are necessary in order to obtain production flexibility.

Theoretically, an FMS should have all of these types of flexibility, but this is not always the case in practice, due to the costs which are often very high (Browne, Dubois, et al., 1985; Groover, 1987; Nee et al., 1994; Lee, 1994a).

4.6. PRODUCT-PROCESS MATRIX AND OPERATIVE FLEXIBILITY STRATEGY

The productivity of a manufacturing system (and the production factors it uses) varies depending on whether the process used is a job-shop, batch process, broken line, continuous line or a continuous flow process. High pro-

ductivities are linked to mass production, thus large volumes, which make it possible to achieve high economies of scale. Thus productivity increases progressively from the job-shop to the continuous flow, parallel to the increase in the size and specialization of the systems, their degree of use; it increases when the layout changes from process to product, when cycles are formalized and tasks standardized.

However, the productivity of a system does not depend solely on the type of process adopted. It is also conditioned by how the process is carried out, thus by its production efficiency. Thus once a certain process has been defined, whether it be a job-shop or continuous flow, productivity will depend on the utilization, the production rate, the skill of labour, the effectiveness of the maintenance system, and so on.

Each type of system therefore has a maximum productivity that may theoretically be achieved, based on its intrinsic features; in practice, the actual productivity of the system will be determined by the efficiency of the process. For example, a continuous line certainly has a high theoretical productivity, but if it is underused, with inexperienced labour or frequent interruptions, the actual productivity will be decidedly much lower. In addition, the processes with a greater theoretical productivity, thus continuous ones, operate at a higher degree of efficiency with respect to flexible processes. Productivity and efficiency are reflected in determining the unit production cost. This is lower the higher the productivity of the system; thus the need to reduce costs means that production factors are used more efficiently.

The concepts described may be examined in greater detail by examining the model proposed by Hayes and Wheelwright (1979), known as the "product-process matrix" (Figure 4.2), which serves to highlight the correlation between types of product and types of process. The columns and rows of the matrix describe:

– the type of product mix;
– the type of manufacturing processes.

The product mix evolves from unique, custom-made productions to the production of many models in relatively low volumes, to the production of few models in high volumes, to standardized productions in large volumes. The process models move from a flexible, fragmentary process to an automated, rigid continuous-flow process. Between these two extremes, a vast range of solutions is possible in terms of flexibility and productivity and greater or lesser integration. Various critical management objectives corre-

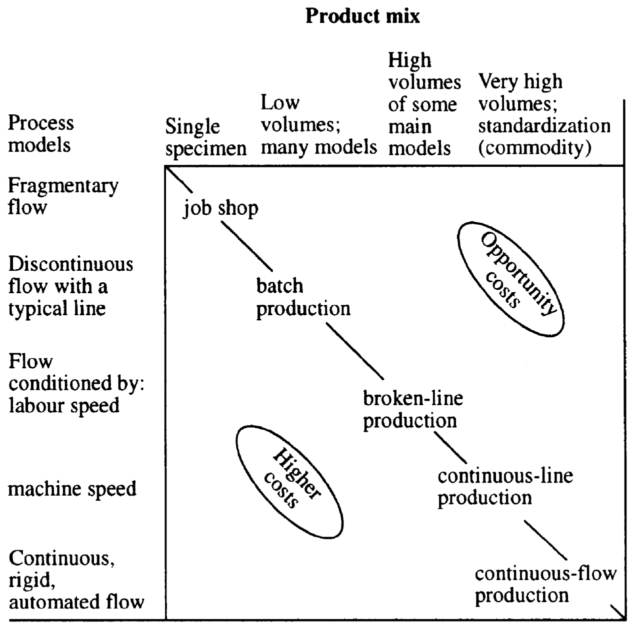

Figure 4.2. The "product-process" matrix

spond to each product mix and process model, thus different critical choices that the management must make (specific managerial skills are related to each choice).

The important point of the model is the correspondence that must exist between the type of manufacturing mix and the type of product used in order to achieve an ideal solution. The ideal product/process choices are arranged along the diagonal of the matrix, from the upper left- to the lower right-hand corner. Only by following the diagonal is it possible to identify the most efficient combination between the type of manufacturing process and the product mix.

The manufacturing system is optimized whenever one is located on the main diagonal of the matrix: this diagonal lists the five types of pure manufacturing systems, traditionally identified by doctrine, each of which represents the ideal combination of product and process. Once a given product mix has been selected, the ideal manufacturing system is the one capable of making it at the lowest possible cost, and thus the system that maximizes productive efficiency (by minimizing the unit production cost).

An examination of the product-process matrix leads to the following deductions: along the diagonal, from top to bottom, we move from manufacturing systems with low productivity and high flexibility to manufacturing systems with high productivity and high rigidity, due to an increase in the

volumes and reduction in the models produced. While theoretical productivity increase when the line is followed in this direction, the efficiency (theoretical, not operative) of the system is always greatest along the entire diagonal.

Thus, along the vertical axis of the matrix, theoretical productivity increases from top to bottom, passing from flexible to rigid processes; but the efficiency of each process is maximized only along the diagonal. Therefore, once a point has been set on the vertical axis, the intersection with a single point on the horizontal axis results in an actual productivity equal to the theoretical (thus maximizing efficiency). We must always remember that as productivity increases along the diagonal, the maximum efficiency that may theoretically be achieved also increases, as long as it is related to intrinsic features of the process, but this maximum efficiency is possible only along the diagonal (obviously without taking into consideration any operative inefficiencies that might occur, such as inactivity, slow work rates, etc.).

Thus, in conclusion, the business must position itself on the main diagonal of the product-process matrix, because here the manufacturing system is perfectly focused on the priority objective (related to the product mix) and thus operates ideally. The diagonal clearly shows the trade-off that exists between productivity and flexibility, often mentioned earlier. This trade-off can be diminished today by flexible automation.

The unit cost is minimum along the diagonal; different types of additional costs are sustained above and below the diagonal (Figure 4.2). Consider, for example, that a company tries to manufacture low volumes of a wide range of products using a continuous, rigid and automated process. This combination, located below the diagonal, is clearly inefficient, since the process should be frequently interrupted and retooled in order to ensure the level of flexibility necessary for the production of many different product models, set up for small batches. The choice proves to be not only inefficient, but also extremely costly: the investment in automated systems, the cost of continuous retooling, the start-up times and considerable scrap would all be a great waste.

Above the diagonal, other types of costs appear: suppose for example that a highly standardized product, consumed in large volumes, is produced with a discontinuous process (in batches, for example). Here again the choice is completely inefficient, not because of the extra costs due to the purchase of expensive systems as in the previous example, but for all of the operative costs (especially labour) that are very high. This is reflected in a compression of the unit contribution margin. We may therefore state that by not replacing

the generic, high-job-intensity machines existing with specialized, automated machinery, the company misses an opportunity to generate higher profits.

This phenomenon represents an opportunity cost, because by not investing in a more rigid manufacturing process, the company misses an opportunity to earn higher profits. These costs are, however, real, and must be considered such in production decisions.

Thus, in conclusion, the company is positioned at a certain point of the matrix diagonal according to the strategy followed. If it follows a cost-led strategy (at the level of the entire market or a particular segment) it will tend to be positioned within the lower part of the diagonal; if instead it follows a strategy of differentiation (or differentiated segmentation) it will tend to fall within the upper part of the diagonal.

The strategic options mentioned, identified by Porter (1983), represent the classic choice opportunities presented to companies. Cost-led policy is a strategic choice that favours specialization and rigidity; the aim of differentiation is instead flexibility of processes. Thus the company must face the already-mentioned "productivity dilemma".

But technological progress currently makes it possible to maintain a certain flexibility in the downward movement towards the bottom of the matrix diagonal, and to improve the production cycle times of the job-shop and batch process.

These recent developments offer a chance to follow a new basic strategy, known as "operative flexibility".

This strategy begins with the need to carry out a production with batches that may even consist of a single unit, but at the same time not preclude the production of large volumes; it expresses a craftsman-type manufacturing capacity, together with the high efficiency levels typical of a continuous process, thanks to the very short machine retooling times. By combining the strong points of department production, line production and craftsman production, the strategy of operative flexibility encourages adaptation to various production needs, as it can produce a large series of products within the same technology. This adaptability to specific market needs is possible thanks to flexible production systems.

The flexibility strategy, whose adoption is made possible by the system, implies not only a chance to introduce new products, but also processing elasticity within the set product mix, flexible product quality, production volumes and system response times. In short, all five types of flexibility identified by Slack are ensured.

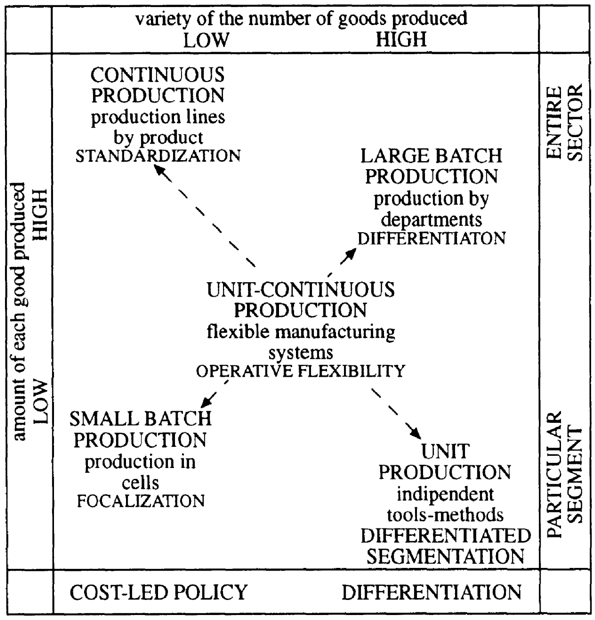

Figure 4.3. The "production process-technology-strategy" matrix

Caputo offers an interesting matrix (Caputo, 1986) which relates production processes, the technology applied therein and the strategy followed to the quantities and variety of goods produced and the main strategic options suggested by Porter. Figure 4.3 shows this matrix; the role of flexible production systems in offering new strategic opportunities for companies is easily comprehensible.

In conclusion, we recall that in such systems, the time reduced by the system, in set-up times and the reduced stock levels, number of product defects, direct labour and spaces, all ensured by a CAM system, are the elements of rationalization that make the terms "flexibility" simultaneously compatible with "productivity", traditionally considered the halves of a dichotomy.

The problem of achieving efficiency in relation to the scale on the one hand, and to the variety/variability of products on the other, is equally significant.

The former, and important, aspect has been recently dealt with broadly by Scazzieri (1993). He has clearly pointed out that expansion and contraction of the scale is not necessarily related to a more or less efficient result. Instead, a scale-efficiency relationship can be identified and achieved if the manufacture manages to satisfy a "maximization model" for technical adoption.

In other words, each form of adopting a technology corresponds to a different scale, capable of achieving high levels of efficiency. Therefore,

there are no fixed rules valid in general for achieving the highest efficiency according to the adopted scale (Haustein and Maier, 1985).

This conclusion is just as valid for product mix. According to its breadth and form of manufacture, in "flexible" systems it is impossible to establish a general correlation between optimizing production factors and minimizing costs (efficiency) without defining the model of technical practice to be followed, once the desired objectives have been identified.

4.7. DEVELOPMENT STRATEGIES FOR FLEXIBLE SYSTEMS

From an analysis of the empirical experiences in the diffusion of FMS, it is possible to identify various development strategies for these systems, which arise from the different styles or philosophies adopted by both manufacturers and users. Camagni (1988) identifies basically three strategic models: the Japanese, American and Italian models.

The Japanese model may be defined by the following elements:

- the technological development process springs from the analysis of the individual basic functions/operations, thus most of it takes place within the adopting company;
- the first step includes the simplification, standardization, optimization of all operations and procedures, even within the traditional production process, in order to achieve the objectives of saving time and costs: examples of this are applications of the just-in-time system both inside and outside the company, the standardization of moulds and materials in order to reduce the set-up times, the study of all elements that make work easier;
- the automation of processes and software connections are created only after the production process has been analyzed, understood, simplified and optimized as above;
- even after the major investment has been made, continuous incremental innovations are made to the processes by small teams of engineers, assisted by technicians;
- the fundamental objectives of the adopted process are plant flexibility, simplification of managerial practices and the increased productivity of a quantitatively stable work force;

In synthesis, this is a typically bottom-up method, focused on the user (who often builds the machine himself), well suited to diffusion not only in large-sized companies but also small- and medium-sized companies.

The American model appears to be characterized, on the other hand, by the following elements:

- emphasis on the system more than on its components, and a goal for prefiguring the CIM (Computer Integrated Manufacturing);
- consequently, a strategic presence of the integrator system and special attention given to the system software, as well as to all of the problems of standardizing and defining the interface protocols between different configurations and systems, and advanced and frontier applications of display and artificial intelligence systems;
- the overall system, generally larger than its Japanese equivalent and with great attention to integration with the production management and the administrative/management system in general, is put together through one giant financial and technological effort, then subsequently changed very rarely;
- as a consequence, the degree of flexibility is much lower;
- the most highly-emphasized objective is to reduce the use of direct labour, in addition to increasing the quality and reliability of the entire process.

Overall, this is a typically top-down approach, with long-term objectives, mainly suited to the needs of large-sized companies seeking plant flexibility.

Through the experience of the largest manufacturers and users of Italian flexible systems, a third route can be identified, an Italian approach to the automated factory, which lies between the two extreme archetypes above, characterized by:

- initial emphasis centred around the product-process, thus on the specifics of the technology and its potential;
- broad attention paid to integrating process and product innovation, in order to maximize the technical possibilities of automatic manipulation of the new technologies on the one hand, and to take advantage of their potential in terms of product/market on the other: the product is designed along with the technology to produce it;
- a significant role played by the technologist and machine builder, who gradually expands his strategic competency to the overall system; even in his market image, the pure systems analyst does not yet provide all of the guarantees, in this early development phase, that the user requires and sees mainly in the "mechanic";
- special attention paid to the incremental integration of increasingly vast areas, both in machining, designing and managing the factory;
- greater clarity of the organizational and strategic implications of the technological change.

Basically, this model may well be considered an intermediate model, which has in many cases already achieved excellent results, due to its greater sensitivity to the features and potential of the new technologies; it is closer to a bottom-up approach given its incremental nature, but has in common with the top-down approach careful attention paid to the final objective of integrating the various sub-systems. It could be summarized by the slogan "top-down planning and bottom-up implementation".

The current bottleneck of this model is represented by the reduced power of the computer/systems component among manufacturers and users of new technologies. However, to this end, the instrument of co-operation agreements and joint-ventures between mechatronic and computer companies appears to be extremely suited and flexible.

A characteristic of the Italian model, however, which stems from the historical peculiarities of both the market and manufacturing sector, is the prevalence of the partner who supplies mechatronic skills over the one who provides computer skills; this imbalance is destined to last for at least another decade. The basically bottom-up nature of the Italian approach to project engineering, which lies at the foundation of the undeniable success of this model throughout the world, requires this imbalance, at least in the short-medium term.

According to Camagni, the American model is the most productive in the long term, but not in the short term. He feels that the overintegration typical of this model not only makes it difficult to bring plants up to operating level, but in the current state of technology also holds back their flexibility, thus preventing them from achieving the main objective of modern production. On the contrary, the Japanese experience is highly profitable in the short term. Although it is probably difficult to imitate outside that country, it does teach us that many objectives assigned to flexible automation in the United States (such as product quality, process reliability and reducing down-times) can be achieved in a much less costly manner by continually emphasizing management responsibility in all stages of manufacturing, and by involving personnel, rather than installing expensive FMSs (Jaikumar, 1987).

4.8. JUST-IN-TIME MANUFACTURING

The problem of conciliating operative flexibility and economy of running costs within a single manufacturing system does not involve merely techni-

cal-structural considerations, but also technical-functional ones that may be summarized in the need for a manufacturing control system that keeps track of times and co-ordinates the supply-planning-distribution sequence and demand.

One of the major objectives of the JIT system must be a valid control of process stock which, affecting the economic and asset structure of companies, contributes considerably to raising the fixed cost component, which is one of the most important factors of rigidity.

Control is even more necessary if one takes into account the current turbulence of demand, which requires constant adaptation of the product mix offered, thus increasing the amount of obsolete materials and products, no longer usable for production and/or sale. One solution to the stock problem is provided by modular production, discussed earlier: this makes it possible to reduce a high number of differentiated articles into a lower number of common component parts, converting fluctuations in the demand for individual finished products into a much more stable and foreseeable demand for modular parts, considerably reducing stock. In second place, one must reflect that flexible automation has eliminated the times absorbed by production changeovers, making an economic comparison between production and stock maintenance superfluous and thus eliminating the economic batch (Aggarwaal, 1986).

The advantages foreseen in terms of reduced process stock may however be compensated for by failure to synchronize when a certain piece is manufactured and when it is demanded (by the market or by the next operation in the production sequence). It is therefore necessary to be able to manage and co-ordinate the various process stages according to demand: this ability is put into practice in a production scheduling and control system aimed at preventing costs generated by organizational disfunctions which affect the economic result.

There are two basic production scheduling methods:

– push systems: these start with sales forecasts, extended over an established time period, and based on these forecasts develop the production schedule — seen as the orderly sequence of products that must come off the assembly line and be sent to the finished product warehouse, from which they are taken according to actual orders. The stages prior to assembly are scheduled based on the time necessary in order to make a component or semi-finished part and the time necessary for it to arrive on the final assembly lines, together with the others. Activities are planned according to suffi-

ciently small economic lots, so as to be absorbed by demand within a relatively brief period; this makes it possible to keep stock at a minimum, compatible with the "physiological" needs of the manufacturing system. The MRP (Material Requirement Planning) technique, developed in the USA, is inspired by this model;

– pull systems: the planning criteria for push models are overturned. It is no longer production that pushes based on the planned schedule, but rather the market — thus the orders — that determine production, organized according to the flow of parts that descend one at a time, in an orderly fashion, through the stages of the manufacturing process. In this way a "pull" system produces only the necessary material required by the following stage; buffer stock, which in a push system is induced by disturbances that may be generated between two linking phases, is reduced to a minimum — thus the technical stock strictly necessary in order to feed a continuous flow of material. The Kanban technique, developed in Japan, is inspired by the pull system.

The pull system falls within a vaster management and organizational system known as "just-in-time" production (JIT), aimed at an overall rationalization of the manufacturing system. JIT is a set of activities directed at rationalizing the entire production sequence, affecting the process structure from both a technical (plant layout and technological level of machinery) and organizational standpoint (labour organization and timing of operations), to ensure the smoothest possible flow of parts within the factory and along the supply-production-distribution sequence.

The following are the main methods for implementing the just-in-time model (Lubben, 1988; Voss, 1988; Voss and Clutterbuck, 1989; Shingo, 1988; Ansari, 1990; Schniederjans, 1993; Satin, 1991).

– creation of a communication system that links the last operation in the production sequence to the first in the cycle; this system must be flexible to reflect changes in demand in the process itself;

– restructuring professional roles (sets of tasks and duties), to guarantee increased participation by department supervisors and workers in solving operative problems;

– rationalization of the machinery lay-out, to shorten the distance between equipment and to regroup the production structure according to the concepts of cell and group technology. In particular, there is a switch from a department organization to a continuous-flow organization, where long production lines are replaced by a number of smaller, low-capacity lines (each one being located in a single cell), but capable of more easily han-

dling small production batches, to achieve greater flexibility towards mix and volumes;
– introduction of the "Visual Control System". This, made possible by re-sizing the production units, means rapid identification of errors and thus short reaction times;
– reduced set-up costs: this problem may be solved by heavy use of robotics systems. In particular, FMS cells automatically change the tools on operating machines and, by rearranging the entire production line simply by replacing a computer program, reduce system reaction times to changes in demand. The removal of set-up costs make economic lots useless, and thus make it possible to supply one piece at a time, at the precise moment when the information system signals a need for it.

The objectives of JIT are to speed up the production system (reducing lead times at the various stages) and synchronizing the market and the various manufacturing activities (reducing batches and re-absorption times).

The reduction of lead times makes it possible to reduce system inertia, and thus the time interval between the order/forecast and response: the probability of forecasting errors is thus lower. Reduced processing batches (even to the point of individual units) leads to improved flexibility: large lots not only increase the average stock and thus inertial mass of the production system, but can also interfere with change until the material produced has been entirely consumed.

In short, the JIT method potentially makes it possible to achieve lower production costs than MRP (thanks to the smaller process stock and greater line productivity) and a higher product quality (given the smaller number of pieces being manufactured simultaneously on the same line) (Goddard, 1985; Petroff, 1993; Hirano, 1989).

In Japanese companies, which have been using the Kanban system for five or more years, there has been a 30% approximate increase in productivity, a 60% reduction of stock, a 90% reduction of reject rates and 15% reduction of space, as well as excellent results in reducing lead times.

Toyota, the first company to apply the Kanban system, has achieved results that can be modestly described as considerable (Shonberger, 1982).

The possibility of organizing the manufacturing process according to a flow chart might thus be eliminated for those companies who operate in markets where the segmentation of demand, together with the structure of the competition, make the variety of supply extremely important. In truth, when dealing with the problem of simultaneously satisfying the need for produc-

tivity and flexible production, it is a mistake to separate technical-structural conditions (rationalizing the product and the process) from technical functional ones. Product rationalization by classifying similar parts into homogeneous families (group technology) and modular design make it possible to reduce a wide range of articles to just a few groups of products, each of which consists of a limited number of pieces, all of which may be obtained on a single manufacturing line. Given that each line headed by a technological group works on a limited number of parts or products, it may be managed according to JIT.

4.9. AUTOMATION STRATEGIES

There are certain fundamental strategies that can be employed to improve productivity in manufacturing operations.

1. *Specialization of operations.* The first strategy involves the use of special-purpose equipment designed to perform one operation with the greatest possible efficiency. This is analogous to the concept of labour specialization, which has been employed to improve labour productivity. It can reduce the operation time.

2. *Combined operations.* Production occurs as a sequence of operations. Complex parts may require dozens, or even hundreds, of processing steps. The strategy of combined operations involves reducing the number of distinct production machines or workstations through which the part must be routed. This is accomplished by performing more than one operation at a given machine, thereby reducing the number of special machines needed. Since each machine typically involves a set-up, set-up times can usually be saved as a consequence of this strategy. Material handling effort and nonoperation time are also reduced.

3. *Simultaneous operations.* A logical extension of the combined operations strategy is to perform at the same time operations that are combined at one workstation. In effect, two or more processing (or assembly) operations are being performed simultaneously on the same workpart, thus reducing total processing time.

4. *Integration of operations.* Another strategy is to link several workstations into a single integrated mechanism using automated work handling devices to transfer parts between stations. In effect, this reduces the number of separate machines through which the product must be scheduled. With more

than one workstation, several parts can be processed simultaneously, thereby increasing the overall output of the system.

5. *Increased flexibility.* This strategy attempts to achieve maximum utilization of equipment for job shop and medium-volume situations by using the same equipment for a variety of products. It involves the use of the flexible automation concepts explained earlier. Prime objectives are to reduce set-up time and programming time for the production machine. This normally translates into lower manufacturing lead time and lower work-in-process.

6. *Improved material handling and storage.* A great opportunity for reducing nonproductive time exists in the use of automated material handling and storage systems. Typical benefits include reduced work-in-progress and shorter manufacturing lead-times.

7. *On-line inspection.* Inspection for quality of work is traditionally performed after the process. This means that any poor-quality product has already been produced by the time it is inspected. Incorporating inspection into the manufacturing process permits corrections to the process as the product is being made. This reduces scrap and brings the overall quality of product closer to the nominal specifications intended by the designer.

8. *Process control and optimization.* This includes a wide range of control schemes intended to operate the individual processes and associated equipment more efficiently. By this strategy, the individual process times can be reduced and product quality improved.

9. *Plant operations control.* Whereas the previous strategy was concerned with the control of the individual manufacturing process, this strategy is concerned with control at the plant level. It attempts to manage and co-ordinate the aggregate operations in the plant more efficiently. Its implementation usually involves a high level of computer networking within the factory.

10. *Computer integrated manufacturing (CIM).* Taking the previous strategy one step further, we have the integration of factory operations with engineering design and many of the other business functions of the firm. CIM involves extensive use of computer applications, computer data bases, and computer networking in the company.

As we have seen, automation may be applied to various components of the production process and to various business functions. However, in order for the advantages of applying automation to production processes to be fully realized, the respective automated systems must be fully integrated. Such an integration is the task of CIM which, despite its name, does not refer solely to technical production, but represents a combination of

CAD/CAE, CAM, MIS (Management Information System) and any other automated business activities. In practice, this integration would represent the possibility of various company functions to access the same information base (Data Integration), which is automatically updated and changed by any transaction made by any business function (Transactional Integration); in addition, from an operative standpoint, there should be full compatibility between the various software applications used and the possibility of accessing them and using them in a standard fashion (Operational Integration).

In truth, the concept of integration defined above is still far from being fully realized. While it may be fairly simple to automatically update a data base within a traditional data processing system, its complexity increases when the manufacturing aspect is involved. For example, consider that by simply changing one detail of a product design leads to consequences for production (processes, tools used), for management (changes in costs and orders), and for the design function itself (material resistance, calculations regarding the machinery dynamics).

In most companies, it is currently difficult to guarantee integration even within the individual functions. In design, for example (including the various stages of analysing the state of the technology and the market, basic and applied research, prototype development, assessing the economic convenience of production, process development) the flows of information exchanged within each phase and among the various phases are so numerous and consistent that it is imperative to use specific computerized systems (CAD/CAE) (Groover and Zimmers, 1984; Besant and Lui, 1986; Bo and Lillehagen, 1983; Gero, 1985; Duncan and Yuille, 1984). Even so, currently the term CAD/CAE tends to imply a concept of solely the project design stage, excluding other functions such as information research, assessing the feasibility of projects, and all decision-making processes in general. This is true because, even today, the computer is mainly seen to be a simple and fast data storage container. The development of artificial intelligence will make it possible to overcome this view, and may facilitate functional integration.

While difficulties are encountered in integrating a single business function, the problems for integrating the various functions together are still greater. The automatic transfer of information between the design function (CAD system) and production system (CAM) is possible only in the case of widespread adoption of numerical control (NC) machines. Without these, the two functions mentioned remain essentially manually connected. Similarly, the manufacturing function (CAM) and the managerial function (MIS)

can be interfaced only if numerical control machines are present to allow data to be gathered on the production process directly from the source. In addition, the graphics used by CAD systems tend to reproduce manual drawings, and while it is ideal for drawings to be read by a person, it is not suited for use in a CAM system (Zgorelski, 1987; Ekong, 1987; Almondo, 1987; Miller and Walker, 1989; Sullivan and Ahmad, 1994).

Full realization of CIM is thus subordinate to achieving certain results in research, such as:

- the standardization of application programs and the creation of hardware and software increasingly modular and expandable and/or modifiable by the user;
- the definition of more precise product description languages suited for use by automated systems;
- the development of artificial intelligence techniques for use in CAD/CAM and MIS systems.

4.10. FROM ECONOMIES OF SCALE TO ECONOMIES OF SCOPE

For decades all technologies were based on economies of scale, in the sense of minimizing cost by maximizing production volumes; the new flexible technologies are based instead on "scope economies", so that technical and economic efficiency due to the variety of products rather than volume.

Scope economies exist when the same plant can make different products at lower costs when they are combined together rather than when they are separated (Morroni, 1992).

For example, a CNC machine tool can work on a dozen units of the same model in succession or, with no problem, on ten different models of products in a random sequence (obviously within a family of models). The times (and thus also the costs) for changing from one product to another are negligible, given that the set-up of the machine requires little more than reading a computer program.

Substantially, computer-based technology reverses the historical trend towards specialized hardware, placing the emphasis on specialised software instead (Priore and Sabel, 1987).

When the economic manufacturing lot comes close to one unit, and achieving a balance between the equipment and storage costs thus ceases to be a problem, manufacturers find it just as economical to manufacture one

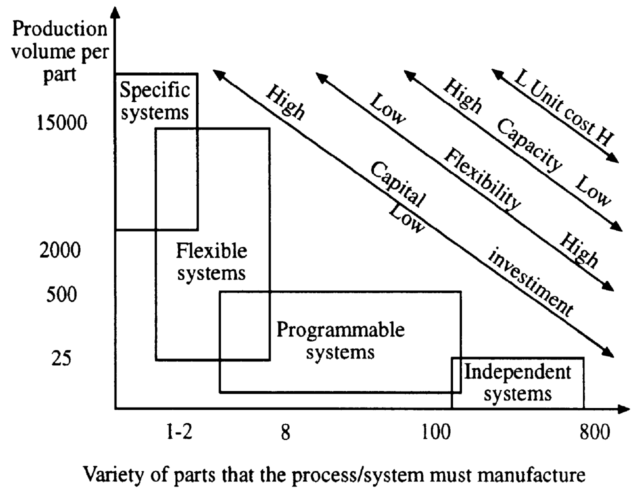

Figure 4.4. Technological options relative to the conditions of flexibility and elasticity

unit as to manufacture many. Obviously, it is economical to reduce the economic lot to one unit only if company marketing strategy centres around personalized products and frequent changes, and if the research and development sector can provide a constant flow of product changes and process improvements. Thus the link returns between the business strategy and manufacturing process adopted; the latter may now be better specified in terms of available technological options, each corresponding to a certain strategic option relative to the variety of parts that each system must produce, and the production quantities for each part (Vicari, 1986; Mather, 1988).

The configuration of a process may be based upon the following types of technologies:

- that are independent from the product design, and which may thus be used for different products and projects (for example, independent numerical control machines, simple manual tools);
- that are programmable and thus able to operate with a range of different configurations, each of which reflects a different product design (for example, computer-controlled mechanical workstations, known as "machining centres");
- that are just flexible enough to host a range of product designs within a single configuration (for example, a mixed production line, which often evolves towards an FMS);
- that are rigid, thus specifically dedicated to a single product design (for example, an automated continuous line).

Figure 4.4 illustrates the concepts described.

The choice of configuration represents a large commitment undertaken by the company, a commitment that tends to last longer than both the product design and the market characteristics. Products generally move through their life cycles more quickly than the hardware of the manufacturing system can be changed. For this reason, in certain product/market conditions, programmable and flexible technologies take on a special importance, since they allow continuous, precise and economical responses to market changes, quickly reprogramming the existing hardware for new products. In other words, these technologies make it possible to achieve scope economies.

4.11. PRODUCTION DECENTRALIZATION

A complex product may be created by a single business, although the manufacturing technology must be divided into various stages, or the various stages may be carried out by different companies, even physically quite far apart.

The decision to manufacture in either of the two ways — which we might call integration/concentration and decentralization, respectively — depends on various factors.

Manufacturing decentralization — which may be defined as a vertical "disintegration" of the manufacturing processes, and thus plant specialization and the division of labour among companies — offers the following advantages:

- *optimal production unit size*: if a company develops internally all processes necessary for its final production, it risks an unsatisfactory yield. It is more productive to use sub-contractors specialized in equipment or professional skills. By working simultaneously for various companies, they can develop "economies of scale", to the benefit of all clients who could not achieve them individually;
- *specialization of final producers*: by freeing themselves of part of the commitments of manufacturing, the final producers can concentrate their efforts on strategic functions such as research, engineering, final assembly, distribution;
- *elasticity in the event of sectorial setbacks*: some sub-contractors have a technical specialization that allows them to work for various industrial sectors. In the event of a recession in one sector, they can therefore amor-

tize the setback in business, to some extent, by looking for orders in other markets;

– *greater productivity of small- and medium-sized companies*: the response elasticity possible in the event of sharp changes in production, the flexibility of the technical-organizational structure, the absence of information leaks typical in an over complex hierarchical structure, are all productivity factors of smaller industrial units, such as those of the sub-contractors themselves.

Even if they do not maximize the internal scale economies, management is easier and thus more effective for these smaller units;

– *innovation and technological research*: due to their high specialization, some sub-contractors are valuable consultants for clients. They must therefore develop a constant applied research, and be capable of innovation, or else risk being replaced by more advanced suppliers.

The above points often lead to achieving a good level of flexibility of the entire production system, to the point that many industrial firms have and continue to make use of them with determination, in order to deal with the increased turbulence and variability of the markets. This turbulence is substantially due to the instability of the markets, developments in the quality-quantity of demand and the rapid technological progress of materials and processes (Zanoni, 1984).

As far as market instability and the quantitative development of demand are concerned, it may be noted that while on the one hand companies need to look for production combinations capable of ensuring sufficient elasticity in order to deal with changes in demand, on the other there is also the need to use plants and machines with a production capacity capable of taking advantage of economies of scale at each stage of the cycle.

This situation leads to the requirement of limiting the risk of unused capacity, with respect to markets that may undergo setbacks and recessions, and thus induces companies to convert the fixed component of cost into a variable by increasing their use of outside processes and thus decreasing the rigidity of the technostructure in relation to market oscillations.

The qualitative development of demand, by changing the competitive process and the consequent marketing policy of businesses, has forced these to set up a heavy differentiation of the supply and diminish the life-cycle of products: in short, it has required companies to have a considerable operating flexibility. This flexibility was achieved by resorting to the supply and/or sub-contract market, purchasing semi-finished products and hiring specialized firms to

manufacture components. In particular, in the case of purchasing a component on its specific market, suppliers and purchasers play different but complementary production roles: market or complementary production relationships arise between them, which become mere commercial transactions, without any particular form of co-ordination among companies (Silvestrelli, 1984).

This situation is generally found in the markets for standardized components or semi-finished parts. Instead, for special products not available on the market, the company hires an outside contractor to do the manufacturing, with which it sets up some form of collaboration that goes beyond the limits of simple complementary production. The adjustments between client companies and subcontractors concern both quantitative and qualitative aspects: the client company and sub-contractor enter into a relationship of actual co-ordination. These relationships may be so strong and consolidated that the subcontractor's production is dedicated to the client company alone. In this case we refer to a "satellite company", and we find ourselves faced with an especially interesting organizational model, due to the fact that often the economic-production co-ordination relationship between client and "satellite" subcontractor are so deep that they lead to actual "integrated extra-company organisms", also known as "contract groups".

As far as the technological innovation of processes and materials is concerned, its increased complexity has made innovative management of all the integrated technological cycle increasingly difficult for companies, even large ones. The difficulties in production management lead them to farm out the phases of the production cycle for which technological innovation is not conveniently possible internally. Basically, as Silvestrelli observes (1979), decentralized manufacturing offers individual companies the advantage of not having to be familiar with the technical evolution of the raw materials used, and all the technology in the production cycle.

In conclusion, the variability of demand and the need for technical-production elasticity, together with competition in innovation and the need for management flexibility, have contributed toward making companies approach a heavy "vertical disintegration" of the manufacturing cycle, and thus towards a more extended division of labour among companies.

Within this area, we can distinguish situations in which the satellite company is decidedly "submissive" to the will of the client, from situations in which the relationship moves away from all connotations of subordination, to take on features of equality and mutual support. The latter instance is a form of "evolutionary decentralization", in which dependencies are not in a

single direction, but bound together in a close network of relationships that implies a structural reorganization of the manufacturing sector.

The decentralized system offers forms of "expandability" and "flexibility". It is first of all "expandable", in the sense that it makes it possible to absorb positive variations in demand with relative ease: the increase in production capacity required by client companies is farmed out among a large number of smaller companies, who split up the variation between themselves. In addition, these end companies, which do not have high fixed costs to bear, since they are specialized in the end of the cycle where machinery investments are modest, can absorb positive or negative variations simply by changing the number of variable production factors and, at peak times, resorting to subcontractors with a proven work quality. The system is also "flexible", because it makes it possible to quickly implement a mix of differentiation policies without sustaining high changeover costs. The low capital intensity of the end companies, not equipped with specialized — and thus dedicated — machinery, makes it easy to alter and change production within a conveniently admissible interval. At the same time the supplier system, characterized by a large number of production units, is nearly always able to provide the semi-finished part or specific component required by the customer, since it is highly probable that a supplier exists who is capable of satisfying special needs.

However, also and especially in the case of decentralized production, there is a need for "just-in-time" production, to avoid the inconvenience of down-time and storage problems.

As far as the environmental context is concerned it is obvious that the Japanese situation cannot be easily reproduced in the West: Japan has a heavy industrial concentration due to the lack of space (and thus the need to eliminate stock to gain space is an incentive to adopt JIT, which in order to be effective requires companies to be located within a limited area), while in the United States the travelling distances may be enormous.

On the other hand, the dominant business culture, which in the West is closely bound to economies of scale and the economic lot, may find it difficult to interpret production as a sequence of parts proceeding continuously along the entire path. Furthermore, that same dominant culture must interpret the relationship with suppliers (or sub-contractors) differently.

In conclusion, the essential phenomenon that involves the company and makes it flexible is "externalization", or the increasing replacement of company internal circuits with a network of relationships with other companies.

The production capacity no longer identifies the field of company, since by networking with other companies (both upstream and downstream) the company can operate efficiently, acquiring the various production services and co-operating to develop joint innovation projects. The company becomes a "complex" operator of the network in which it is involved: all of the strategic and organizational variables can become mobile, flexible with respect to the innovative projects to be interpreted; the company can build up or down quickly and easily, while rigidity and stability may become attributes of the overall network, which moves to the extra-company level (Rullani, 1988; Lorenzoni, 1983, 1986 and 1990).

The decentralized model is therefore expandable and flexible, but some elements of rigidity may also be pointed out which, if not appropriately handled, may cancel out the positive features in terms of ability to respond to variations in demand.

The trend to decentralize the production during the previous decades has given origin to "agglomerated structures", in specific geographic areas, which are "organizationally and economically integrated" areas, and which are usually called "industrial districts" or "Meccano structures" (Lee, 1994b; Gobbo, 1989; Utili, 1989).

An industrial district is an agglomeration of manufacturing and service companies within a limited geographical area, within which there is integration between different companies combined with high flexibility, due to decentralized production.

A rapid analysis of the basic features describing a district, in the most highly-developed forms of decentralization, leads to the observation that the success of participating companies is due to three typical economic components: specialization economies, transaction economies relative to the relationships between companies, and those relative to relationships between companies and workers. These components are closely linked together, and may be considered as different forms of agglomeration economies.

Both transaction and specialization economies assume, in the end, a high labour flexibility, in terms of both quality and quantity.

The "Meccano" structure is another industrial structure — made up of smaller companies — in which the companies that produce individual parts or services are mutually integrated, creating an extremely high number of goods.

In this system — whose main prerogatives are once again "flexibility" and "system-level economies of scale" — the individual company may remain small and specialized and express a high innovative capacity.

It is now a matter of argument whether there are crisis elements in industrial districts, which compromise their competitiveness and functionality.

This consideration is based upon the hypothesis that in the late 1980s, with respect to the beginning of the decade, certain contextual aspects took on greater significance; these aspects could penalise the competitiveness of industrial districts. From the standpoint of competition factors, it is necessary to greatly increase the "service" content of exports; companies are called upon to put together more complex development strategies, based much more on quality than on price. The farthest markets are growing rapidly, as well as the markets with greater barriers to entry in terms of penetration costs (Onida et al., 1992).

One of the most important causes of the success of districts was represented by the innovative capacity of the companies. The district is, by definition, an environment in which information circulates very rapidly, including everything that concerns improvements in products or processes; this circulation is largely based on interpersonal contact and direct observation, thus generating learning processes by the workforce. The "industrial atmosphere" that reigns in the district has a great capacity for diffusing innovation, also by significantly reducing the costs of information without a parallel increase in co-ordination costs, as would occur in a large company (Bianchi, 1989). In the structure of district companies, even small ones, the introduction of process innovations by purchasing new machinery has never presented any particular problems; on the contrary, this fundamental channel for introducing technical progress has always represented an important element of competitiveness.

The industrial culture typical of districts, almost by definition, is a culture that does not generate radical innovation, but moves, improves and deepens the paths of its own manufacturing tradition. When the industrial culture of a district is faced with exogenous technological shocks, it may encounter considerable difficulty in dealing with them; this may be especially true for computer-based innovations. More generally, there are fears that "district life is going through a transition stage, in which the problems of technological changeover are the most evident: signs of growing and inevitable conflict are noticed between the old industrial culture and the new culture, especially conditioned by frequent and rapidly-evolving electronic innovations" (Alessandrini, 1989; Crivellini, 1982).

4.12. FROM SYSTEMS TO NETWORKS: NON-COMPETITIVE RELATIONS

Several transformations are occurring in the productive structure that give rise to remarkable effects on the economic systems as a whole.

As all the productive activities have a multi-dimensional nature (Scazzieri, 1993) and the choice of technology may be affected by compatibility factors within the overall system (Quadrio Curzio, 1986; Quadrio Curzio and Pellizzari, 1991), attention must be paid to such transformations, considering also the globalization of markets on one side (Ohmae, 1985) and the strong relationships with the local economic environment on the other (Pasinetti, 1993).

One of the greatest shortcomings of traditional economics is to have limited the study of the external relationships that the company establishes with regard to the problem of competition, which has been the central point of the market theory. In a context in which the company is highly dependent on external resources, however, it is necessary to give some theoretical attention to "non-competitive relationships" between companies: that is, to the relationships that companies establish with one another, not as competitors but rather with the aim of reaping the advantages of specific complementarities on the levels of technology, production, finance and marketing.

Non-competitive relationships are not necessarily to be traced *tout court* to relationships that companies establish outside of a competitive context in the narrow sense. Consider, for example, the relationships along the vertical chain of production (relationships with component manufacturers, with service industries and subcontractors, with distribution networks, with the servicing network, etc.); the co-operation in technology and research in specific projects of particular importance or involving high risk; the forms of integration of several marketing networks; the joint ventures which give the advantages of financial integration and risk distribution, etc.

What should in any case be underlined is the inconsistency of rigidly separating non-competitive and competitive relationships, because the interweaving of these two kinds of relationships is becoming more and more intense.

The traditional formula, typical of the large company, of internationalization through direct integration is increasingly often substituted by other forms which allow us to appreciate the extent of the transformations involving the large company and its role in the economy of the 1980s. These forms include:

– the development of so-called new product or business departments and of divisions specialized in hatching up innovations (new venture divisions); these constitute project units with the aim of initiating innovative activities, and with considerable experimental independence and mobility;
– the creation of new small-sized companies, possibly with a minority shareholding in the hands of the company of origin, entrusted to internal technicians and managers, with the aim of developing innovative activities in an organizational framework separate from the larger company, establishing links and co-operation between units that are managerially distinct rather than between divisions of the same company;
– the constitution of a series of relationships or contractual agreements with external specialized firms, firms which are sometimes originally promoted by the large firm which uses its services, in such a way as to utilize the entrepreneurial ideas and capabilities available in that context;
– the development of agreements and joint ventures between independent companies for specific projects (for the production of a component, or the development of a technology, or for the joint use of a certain marketing function). This type of agreement gives rise to committed relationships with outside companies because they bring into play genuine pluralism and subjectivity, and bring together companies that are different from the standpoint of their history, their culture, and the kind of language they use, through involved relationships which may notably change the companies themselves;
– the development of standard technologies or special languages which give way to pluri-entrepreneurial formations characterized by the common adoption of the same code, and thus by the possibility of making complementary products and processes;
– the development of company networks which adopt, through licensing, the same technological culture, thus activating a process of learning and reciprocal exchange of know-how in reference to the specific development experience of the common technology;
– the construction of "triadic alliances" in the search for strategic complementarities between companies which are based in different geographical and cultural areas.

The internationalization of companies is conditioned by two different principles: companies must become more and more "global", but at the same time they must be solidly rooted in a given context; that is, they must be "national" (Levitt, 1983).

The development process of an economy, partly because of the new characteristics of the technology, takes place not so much in terms of quantitative growth, as Vaccà has pointed out (1986, 1989), but rather through the close examination of the differentiations (variety), through a continual innovative redefinition of them (variability), and through the appropriate, selective use of variety and variability in relation to specific uses.

The acquisition of external economies of strategic relevance in complex situations almost always requires the development of organizational frameworks of equal complexity, such as systems or networks, frameworks which establish diverse relationships to give them an overall economy, and which cannot be split up on the basis of an atomistic methodology.

When relationships between companies are organized as a system, a plurality of ties (some of which may be contractual) tend to stabilize themselves and be consolidated around a nucleus, thus giving rise to a genuine structure of relationships which tend to reiterate themselves with the same modality; that is, they become routines. When they are organized in networks, a plurality of relationships are developed through the use of a special language that distinguishes them from the companies outside the network. A growing percentage of the relationships between companies is nowadays mediated through the use of special languages which allow different companies to effectively communicate experiences and knowledge whenever these are highly specific and potentially complementary. In reality, systems and networks can coexist in common and direct transactions; however, as they are different forms of external organization, they are to be considered as separate from a theoretical point of view.

Since there must be a plurality of special languages, companies are in fact part of every existing network. The passage from systems to networks calls into question the power that was associated with the previous system of relationships and with large-scale organizations. In this way, the identification of the company with a predetermined structure breaks down.

From the "company-as-structure", settled in its technological and organizational frameworks, one thus passes to something that could be called the "company-as-project"; that is, a productive organization that is a result of an entrepreneurial choice of innovative planning, less and less conditioned by pre-existing structures and more and more justified by current or expected opportunities. In the light of all this it should be obvious that the concept of scale, in the traditional sense, is now to be considered outdated. The thrust of the current technological trends is in fact that of overcoming the hierar-

chical and cumulative reasoning that was associated with the development of modern technology until recently, and of asserting instead a very different logic, that based on the interaction and mobility of organizational frameworks. As Colombo (1985) has observed, "the concepts of causality, sequentiality, linearity and hierarchy are substituted by the concept of functional interaction" between distinct factors and processes, each of which is endowed with its own self-propulsiveness. In other words, the nature of the fundamental relationships conceptualized in economic theory is changing; the relationships between the various segments of a productive cycle, those between supply and demand and between the different companies in a given sector can no longer be described according to stable, optimal distinctions and structures that are consolidated over time. They are defined, on the contrary, by the changeable conditions of interaction which requires new and different organizational frameworks from one occasion to the next.

This is also true for that boundary between external activities and internal activities which constituted the pivotal point of the traditional theory of scale. In reality, technological progress, in its present configuration, continuously calls into question the attribution of given activities or functions to each company. Functions such as research and development, planning and marketing, and activities such as systems technology and manufacturing may be collocated differently within the industrial system from one occasion to the next, giving rise to different and mobile forms of the division of labour between companies (Rullani, 1988). There are thus companies in the manufacturing industry, companies which are undoubtedly market-oriented, that dedicate themselves more and more (and sometimes exclusively) to research, planning, marketing and assembly, while for manufacture itself they use other companies that often have no direct link with the final market (companies of this kind can be found, for example, in the electronic systems technology and the automobile industries).

In this new reality, there is clearly a new role for marketing, which nowadays is to be understood above all as a function of the creation and diffusion of those special languages that interface between supply and demand and that are necessary in order to use technological flexibility to its best.

As a final remark, the increasing interrelationships between evolution of technologies and structural change must be suitably measured by means of specific indicators (Barbiroli, 1995) and analyzed in order to quantitatively and qualitatively evaluate trends and effects, both at national and international levels.

Chapter 5

TECHNOLOGICAL DYNAMICS, EFFICIENCY AND PRODUCTIVITY

5.1. MEASURING THE SEVERAL ASPECTS OF TECHNICAL AND ECONOMIC EFFICIENCY OF PRODUCTION PROCESSES

The efficiency of a production process is usually measured by means of a few suitable indices: the conversion rates of energy and materials used in the process, and the productivity levels.

While the measurement of the conversion rates of energy and materials has become routine in all manufacturing companies without any specific theoretical elaboration, the measurement of productivity has stimulated many theoretical contributions (Jorgenson and Griliches, 1967; Gold, 1955, 1971, 1987; Cowing and Stevenson, 1981; Kurosawa, 1991; Diewert, 1980; Caves, Christensen and Diewert, 1982; Aft, 1991; Christofer and Thor, 1993; Hayes, Wheelright and Clark, 1988), which have been recently outlined by Norsworthy and Jang (1992).

Productivity is a useful but partial tool to measure efficiency, since the performance of the inputs, combined to optimize the output, has several facets, which have increased in number during the last decade as a consequence of the actual new economic and industrial revolution that is taking place in all the manufacturing sectors. For instance, the market demands high quality eco-compatible, and increasingly diversified products; the new features of demand have engendered the introduction and diffusion, by companies, of new production technologies and systems (i.e.: Flexible and Just-in-Time Manufacturing) and of new management criteria (i.e.: Total Quality, including the environmental quality of the process and of the products), which continuously need to be checked and analyzed, especially when innovations at all levels are introduced, and when comparisons have to be made.

Input efficiency is the only aspect of efficiency ever considered important, both at the technical and economic level, even if it has always met great difficulties in being measured in specific processes (Färe and Hunsaker, 1986); indeed, a generic indicator of efficiency is the average unit cost and its vari-

ations or a comparison with the cost of other systems offer a starting point for efficiency analysis (Clews and Leonard, 1985; Coticchia et al., 1993).

The methods now available are econometric and mathematical. The former may be applied to whole sectors, and, consequently, they need aggregated data (Timmer, 1971; Meeusen and Van den Broeck, 1977; Aigner and Chu, 1988; Lovell and Schmidt, 1988; Thiry and Tulkens, 1989; Bauer, 1990; Morrison, 1992; Greene, 1993; Knox Lovell, 1993; Fried, Lovell and Schmidt, 1993).

The latter seem to be suitable for application at company level, but even the most developed seem to be too complicated for their application to actual cases, both on a small and large scale, single or multi-phased.

Several linear programming methods have been developed and illustrated during the last decades.

After the original definition of technical efficiency by Debreu (1951) through a coefficient of resource utilization, and the extension of this work by Farrel (1957), the most suitable methods to explore production and cost frontiers have been elaborated and illustrated by Färe, Grosskopf and Lovell (1985, 1992, 1994), and Russell (1985, 1988, 1990). These economists, after having broken down technical efficiency into scale, input and pure technical efficiency, have applied the linear programming techniques (Dantzig, 1963; Charnes and Cooper, 1961) to modeling production activity, extending an approach initiated by Von Neumann (1937 [1945]), and closely related to the microeconomic programming models developed by Shephard (1953, 1970, 1974) and Afriat (1972).

As a matter of fact, mathematical programming methods provide a useful way of constructing a frontier technology as well as of calculating the distance to that frontier. Nonetheless, a strong resistance among economists regarding adoption of linear programming techniques is widely diffused, partially due to the fact that the results may be altered by noise or measurement error (Schmidt, 1985-86).

With regard to the environmental efficiency of a process and of the adopted technologies, no suitable indices have been developed and applied yet, whereas this aspect of industrial activities has become more and more remarkable and binding.

With regard to the global quality of products, recent research and elaborations have been carried out (Barbiroli, 1989b), leading to the setting up of suitable indices applicable to all types of products. While the degree of flexibility can be easily measured by relating the total set-up time for the possi-

ble configurations of the equipment to the total lead-time, the efficiency of a flexible system needs the elaboration of proper indices.

The aspects that are here considered and proposed for measuring by means of specific indicators are:

- materials cycle efficiency (MCE)
- energy cycle efficiency (ECE)
- process overall environmental efficiency (POEE)
- final product environmental efficiency (FPEE)
- energy cycle environmental efficiency (ECEE)
- product absolute quality efficiency (PAQE)
- product constant quality efficiency (PCQE)
- equipment static operating efficiency (ESOE)
- equipment dynamic operating efficiency (EDOE)
- product mix variability efficiency (PMVE)
- product volume efficiency (PVE)
- input efficiency (IE)

One can observe that all the selected aspects must be considered fundamental for the success of a production activity and the implemented technologies, in a modern sense, especially seeing as they contribute to connoting not only a market orientation but also a socio-economic one (above all, energy, materials, environmental and quality efficiency).

Of course, each of the above listed facets of efficiency may be regarded both at a technical and economic level, and in an interlinked way.

The connections between the twelve aspects here proposed to measure are shown in the "triangle" shaped model schematized in Figure 5.1.

The main problems met following the aim of getting a quantitative measure of all of these different facets of efficiency have been the identification of measurement units able to represent the proper meaning of the various phenomena related to efficiency, and to be comparable in all different fields of production and situations (type, size, location, etc.)

By considering previous methods proposed and implemented for assessing the global advantage and the strategic value of technologies (Barbiroli, 1990 and 1992) and the achievement of new efficiency frontiers in several important production branches (Barbiroli, 1992), it has been possible to reach a satisfying and articulated solution, which is herewith reported and discussed and which has already given comprehensive and reliable information about the "overall efficiency" of a process (Barbiroli, 1996a).

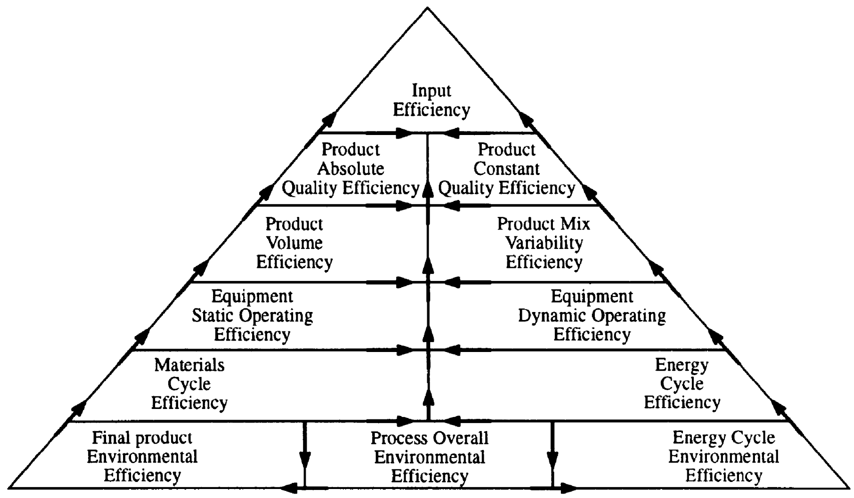

Figure 5.1. Triangle shaped network representing the interconnections between the twelve proposed indicators of the efficiency

Each of the listed aspects can be measured as follows, and how this is done is shown in Table 5.1; for a better application of the indicators, three actual examples have been taken, drawn from international companies, in iron and steel making, car manufacturing and chemical industries (Tables 5.2 and 5.3). The detailed data concerning the case of steel making are not reported for brevity.

The values obtained for each of the three cases are summarized in Table 5.4.

Materials Cycle Efficiency (MCE)

The technical efficiency can be measured by the ratio:

$$\frac{\substack{\textit{quantity of original materials actually transformed} \\ \textit{and included in the products (tons)}}}{\substack{\textit{quantity of original materials} \\ \textit{introduced in the process (tons)}}} \quad (0 - 100)$$

Of course, in all cases of multiple and diversified production the final percentage is obtained by adding the single amounts of materials utilized in the cycle for obtaining the various products.

This expresses the conversion rate of the materials used in the process to the final products.

The higher the percentage the higher the efficiency.

TABLE 5.1. Structure of the various indicators for measuring the technical and economic efficiency

	Technical efficiency			Economic efficiency		
1) Materials Cycle Efficiency (MCE)	Quantity of materials actually transformed and included in the products (tons) / Quantity of the original materials introduced in the process (tons)	(0-100)	(Addition of the single values for the various materials and products)	[Additional cost for materials due to the actual conversion rates (total cost for materials x rate of not-utilized materials) + Costs for upgrading the materials not-utilized in the process] / [Value of the materials actually included in the products (total costs for materials x conversion rate) + Value of the materials included in the by-products] (Addition of the single values for the various products)	(100-0)	
2) Energy Cycle Efficiency (ECE)	Quantity of energy actually utilized in the various phases of the process (MJ) / Quantity of the original energy sources and forms introduced in the process (MJ)	(0-100)	(Addition of the single values for the various products)	[Additional cost for energy due to the actual conversion rates (total cost for energy x rate of not-utilized energy) + Costs for managing and controlling the energy cycle] / [Value of the energy actually utilized in the process (total costs for energy x conversion rate)] (Addition of the single values for the various products)	(100-0)	
3) Process Overall Environmental Efficiency (OPEE)	Total quantity of original and intermediate materials and compounds (potentially polluting) not-released into the environment (tons) / Total quantity of the original and intermediate materials and compounds (potentially polluting) not-transformed into products (tons)	(0-100)	(Addition of the single values for the various products)	Total costs for reducing the dissipative potential of the original and intermediate materials and compounds (potentially polluting) used in the process and not-trasformed into products / Value of the materials actually included in the products (total costs for materials x conversion rate)	(100-0)	(Addition of the single values for the various materials and products)

TABLE 5.1. Structure of the various indicators for measuring the technical and economic efficiency (*continued*)

	Technical efficiency		*Economic efficiency*	
4) Final Product Environmental Efficiency (FPEE)	$\frac{\text{Quantities of non-dissipatable materials into the environment present in the products (natural and anthropic metabolism) (tons)}}{\text{Total quantities of materials present in the products (tons)}}$ (0-100)	(Addition of the single values for the various products)	$\frac{\text{Total costs for reducing dissipatable materials present in the products}}{\text{Value of the materials actually included in the products (total costs for materials x conversion rate)}}$ (100-0)	(Addition of the single values for the various products)
5) Energy Cycle Environmental Efficiency (ECEE)	$\frac{\text{Total quantities of polluting effluents not-released into the environment during the energy cycle (tons)}}{\text{Total maximum (theoretical) quantities of producible polluting effluents in the energy cycle of the process (tons)}}$ (0-100)		$\frac{\text{Total costs for minimizing the dissipative potential of polluting effluents in the energy cycle}}{\text{Value of the energy actually utilized in the process (total costs for energy x conversion rate)}}$ (100-0)	
6) Product Absolute Quality Efficiency (PAQE)	Global Performance Indices (0-100)	(Weighted Mean for the various products)	$\dfrac{\dfrac{\text{Unit production cost for the most valuable product}}{\text{Corresponding highest performance index}} - \dfrac{\text{Unit production cost for the least valuable product}}{\text{Corresponding lowest performance index}}}{\text{Weighted mean for the cost/performance index ratio of the product mix}}$ (100-0)	
7) Product Constant Quality Efficiency (PCQE)	$\dfrac{\text{Maximum detected interval for the performance indices, over time} - \text{Absolute sequential mean difference } \dfrac{\sum \lvert \Delta x\, dt \rvert}{n-1}}{\text{Maximum detected interval for the performance indices, over time}}$ (0-100) (Weighted mean of the single values for the various products, measured using the totality of the products or a statistical sample)		$\frac{\text{Total costs for maintaining the highest constancy of quality properties}}{\text{Total increased commercial value of the products with high constancy of quality properties (obtained by increasing the sale price and/or the quantity of the products to be sold)}}$ (100-0)	

TABLE 5.1. Structure of the various indicators for measuring the technical and economic efficiency *(continued)*

	Technical efficiency	*Economic efficiency*
8) Equipment Static Operating Efficiency (ESOE)	$\dfrac{\text{Total potential working time of the equipment (hours)} - \text{Total break time for set-up and other causes for the consolidated product mix (hours)}}{\text{Total potential working time of the equipment (hours) (Addition of the single times for the various process units)}}$ (0-100)	$\dfrac{\text{Additional amortization share due to breaks for set-up and other causes (maintenance) for the consolidated product mix}}{\text{Amortization share in the average unit production cost for the consolidated product mix}}$ (100-0)
9) Equipment Dynamic Operating Efficiency (EDOE)	$\dfrac{\text{Total potential working time of the equipment (hours)} - \text{Total break time for set-up and other causes after the introduction of new products (or articles) without modifying the process (hours)}}{\text{Total potential working time of the equipment (hours) (Addition of the single times for the various process units)}}$ (0-100)	$\dfrac{\text{Amortization share in the average unit production cost for the new product mix}}{\text{Amortization share in the average unit production cost for the consolidated product mix}}$ (100-0)
10) Product Mix Variability Efficiency (PMVE)	$\dfrac{\text{Number of new products (or articles) obtained by differently combining the inputs without modifying the structure of the process}}{\text{Number of products (or articles) usually obtained in the process}}$ (0-100)	$\dfrac{\text{Average unit production cost for the new product mix obtained by differently combining the inputs, without modifying the structure of the process}}{\text{Average unit production cost for the consolidated product mix}}$ (100-0)
11) Product Volume Efficiency (PVE)	$\dfrac{\text{Quantity of products sold}}{\text{Quantity of maximum producible products}}$ (0-100)	$\dfrac{\text{Maximum obtainable products value} - \text{Actual sold products value}}{\text{Maximum obtainable products value}}$ (100-0)
12) Input Efficiency (IE)	$\dfrac{\text{Optimal total lead-time (hours or minutes) per unit of product, after having optimized all the inputs used in the various phases of the process (elaborated by means of the Linear Programming technique-simplex method)}}{\text{Actual total lead-time (hours or minutes) per unit of product, detected under normal operating conditions}}$ (100-0)	$\dfrac{\text{Actual unit production cost} - \text{Optimal unit production cost}}{\text{Optimal unit production cost}}$ (0-100)

Examples:

A) $$\frac{200,000 \textit{ tons}}{331,000} = 60.42$$

B) $$\frac{2,140,000 \textit{ tons}}{2,512,000} = 85.20$$

C) $$\frac{280,000 \textit{ tons}}{369,000} = 75.88$$

The economic efficiency can be measured by the ratio:

$$\frac{\begin{array}{c}\textit{additional cost for materials}\\ \textit{due to the actual conversion}\\ \textit{rates (total costs for materials}\\ \textit{x rate of not - utilized materials)}\end{array} + \begin{array}{c}\textit{costs for upgrading}\\ \textit{the materials not - utilized}\\ \textit{in the process}\end{array}}{\begin{array}{c}\textit{value of the materials actually}\\ \textit{included in the products}\\ \textit{(total costs for materials}\\ \textit{x conversion rate)}\end{array} + \begin{array}{c}\textit{value of the materials}\\ \textit{included in the}\\ \textit{by - products}\end{array}} (100 - 0)$$

In cases of multiple and diversified production the single values must be added.

The lower the incidence the higher the efficiency.

If the non-utilized materials (original and/or intermediate) cannot be upgraded, the ratio provides the same results as the ratio concerning the technical efficiency.

Examples:

A) $$\frac{22,701,000 \text{ (\$) } x \text{ } 39.58 + 1,210,000 \text{ (\$)}}{22,701,000 \text{ } x \text{ } 60.42 + 2,100,000} = \frac{10,195,056 \text{ (\$)}}{15,815,944} = 64.46$$

B) $$\frac{7,960,000,000 \text{ (\$) } x \text{ } 14.80 + 200,000,000 \text{ (\$)}}{7,960,000,000 \text{ } x \text{ } 85.20 + 550,000,000} = \frac{1,378,080,000 \text{ (\$)}}{7,331,920,000} = 18.79$$

C) $$\frac{71,340,000 \text{ (\$) } x \text{ } 24.12 + 2,500,000 \text{ (\$)}}{71,340,000 \text{ } x \text{ } 75.88 + 3,000,000} = \frac{19,707,200 \text{ (\$)}}{57,132,792} = 34.49$$

Energy Cycle Efficiency (ECE)

The technical efficiency can be calculated by the ratio:

$$\frac{\textit{quantity of energy actually utilized in the various phases of the process (MJ)}}{\textit{quantity of the original energy sources and forms introduced in the process (MJ)}} \quad (0 - 100)$$

The higher the ratio the higher the efficiency.

This expresses the conversion yield of the energy used in the process. When different sources and forms of energy are utilized, the single values must be added.

Examples:

A) $$\frac{2{,}000}{4{,}200}\ (10^6\ MJ) = 47.60$$

B) $$\frac{2{,}000}{2{,}700}\ (10^6\ MJ) = 74.00$$

C) $$\frac{2{,}050}{3{,}300}\ (10^6\ MJ) = 62.10$$

The economic efficiency can be measured by the ratio:

$$\frac{\textit{additional cost for energy due to the actual conversion rates (total costs for energy x rate of not-utilized energy)} + \textit{costs for managing and controlling the energy cycle}}{\textit{value of the energy actually utilized in the process (total costs for energy x conversion rate)}} \quad (100 - 0)$$

The lower the ratio the higher the efficiency.

The single values concerning the various energy sources must be added.

In case where the percentage exceeds 100, it must be considered as if it were the lowest efficiency, i.e. 100.

Examples:

A) $$\frac{19{,}538{,}400\ (\$)\ x\ 52.40 + 1{,}000{,}000\ (\$)}{19{,}538{,}400\ x\ 47.60} = \frac{11{,}238{,}121\ (\$)}{9{,}300{,}278} = 120.84$$

B) $$\frac{3{,}980{,}000{,}000\ (\$)\ x\ 26.00 + 600{,}000{,}000\ (\$)}{3{,}980{,}000{,}000\ x\ 74.00} = \frac{1{,}634{,}800{,}000\ (\$)}{2{,}945{,}200{,}000} = 55.50$$

C) $$\frac{45{,}000{,}000\ (\$)\ x\ 37.90 + 2{,}000{,}000\ (\$)}{45{,}000{,}000\ x\ 62.10} = \frac{19{,}055{,}000\ (\$)}{27{,}945{,}000} = 68.19$$

Process Overall Environmental Efficiency (POEE)

The technical efficiency can be measured by the ratio:

$$\frac{\begin{array}{c}\textit{total quantity of original and intermediate}\\ \textit{materials and compounds (potentially polluting)}\\ \textit{not-released into the environment (tons)}\end{array}}{\begin{array}{c}\textit{total quantity of original and intermediate}\\ \textit{materials and compounds (potentially polluting)}\\ \textit{not-trasformed into products (tons)}\end{array}} \quad (0 - 100)$$

In cases of multiple production, the result is obtained by adding the single values for the various products. The higher the value the higher the efficiency.

Examples:

A) $$\frac{72{,}000\ \textit{tons}}{131{,}000} = 55.00$$

B) $$\frac{624{,}000\ \textit{tons}}{712{,}000} = 87.60$$

C) $$\frac{66{,}000\ \textit{tons}}{89{,}000} = 74.10$$

The economic efficiency can be measured by the ratio:

$$\frac{\begin{array}{c}\textit{total costs for reducing the dissipative potential}\\ \textit{of the original and intermediate}\\ \textit{materials and compounds (potentially polluting)}\\ \textit{used in the process and not - trasformed into products}\end{array}}{\begin{array}{c}\textit{value of the materials included in the products}\\ \textit{(total costs for materials x conversion rate)}\end{array}} \quad (100 - 0)$$

The lower the value the higher the efficiency.

If the ratio exceeds 100, it must be considered as if it were the highest inefficiency, i.e. 100.

Examples:

A) $$\frac{3,256,400\ (\$)}{27,701,000\ x\ 60.42} = \frac{3,256,400\ (\$)}{13,715,944} = 23.74$$

B) $$\frac{1,857,000,000\ (\$)}{7,960,000,000\ x\ 85.20} = \frac{1,857,000,000\ (\$)}{6,781,920,000} = 23.78$$

C) $$\frac{22,500,000\ (\$)}{71,340,000\ x\ 75.88} = \frac{22,500,000\ (\$)}{54,132,792} = 41.56$$

Final Product Environmental Efficiency (FPEE)

The technical efficiency can be measured by the ratio:

$$\frac{\textit{total quantities of non - dissipatable materials into the environment present in the products, as achieved through natural and industrial metabolism (tons)}}{\textit{total quantities of materials present in the products (tons)}} \quad (0 - 100)$$

In cases of diversified production, the single values must be added. The higher the value the higher the efficiency.

This represents the eco-compatibility of the final products, during their whole life-cycle, that may be measured by considering the non-dissipative capacity both of nature (natural metabolism) and of man and his organizations (industrial metabolism).

Examples:

A) $$\frac{200,000\ (tons)}{200,000} = 100.00$$

B) $$\frac{1,498,000\ (tons)}{2,140,000} = 70.00$$

C) $$\frac{245,000\ (tons)}{280,000} = 87.50$$

The economic efficiency can be measured by the ratio:

$$\frac{\textit{total costs for reducing dissipatable materials present in the products}}{\textit{value of the materials actually included in the products (total costs for materials x conversion rate)}} \quad (100 - 0)$$

The lower the value the higher the efficiency. In cases where the percentage exceeds 100, it must be considered as if it were the lowest efficiency, i.e. 100.

Examples:

A) $$\frac{0\ (\$)}{22,701,000\ x\ 60.42} = \frac{0\ (\$)}{13,715,944} = 0.00$$

B) $$\frac{1,327,000,000\ (\$)}{7,960,000,000\ x\ 85.20} = \frac{1,327,000,000\ (\$)}{6,781,920,000} = 19.57$$

C) $$\frac{17,500,000\ (\$)}{71,340,000\ x\ 75.88} = \frac{17,500,000\ (\$)}{54,132,792} = 32,32$$

Energy Cycle Environmental Efficiency (ECEE)

The technical efficiency can be measured by the ratio:

$$\frac{\textit{total quantities of chemical and physical effluents not dissipated into the environment during the energy cycle (tons)}}{\textit{total maximum (theoretical) quantities of producible chemical and physical effluents during the energy cycle of the process (tons)}} \quad (0 - 100)$$

The higher the value the higher the efficiency.

This expresses the eco-compatibility of the energy systems utilized to realize the production process.

Examples:

A) $$\frac{90\ (10^6\ tons)}{450} = 20.00$$

B) $$\frac{10\ (10^9\ tons)}{25} = 40.00$$

C) $$\frac{4\ (10^6\ tons)}{12} = 33.30$$

The economic efficiency can be measured by the ratio:

$$\frac{\begin{array}{c}\textit{total costs for minimizing the dissipative potential}\\ \textit{of polluting effluents in the energy cycle}\end{array}}{\begin{array}{c}\textit{value of the energy actually utilized in the process}\\ \textit{(total costs for energy x conversion rate)}\end{array}}\ (100\ -\ 0)$$

The lower the value the higher the efficiency.

Examples:

A) $$\frac{4,884,000\ (\$)}{19,538,500\ x\ 47.60} = \frac{4,884,000\ (\$)}{9,300,326} = 52.51$$

B) $$\frac{265,400,000\ (\$)}{3,980,000,000\ x\ 74.00} = \frac{265,400,000\ (\$)}{2,945,200,000} = 9.01$$

C) $$\frac{10,000,000\ (\$)}{45,000,000\ x\ 62.10} = \frac{10,000,000\ (\$)}{27,945,000} = 35.78$$

Product Absolute Quality Efficiency (PAQE)

The technical efficiency can be measured by elaborating global performance indices, obtained by coupling the several quality/performance factors and by

calculating intermediate indices through an algebraic method (as proposed by Barbiroli, 1990; Barbiroli and Fiorini, 1992) and, of course, by calculating the weighted mean of the global performance index of each product in cases of product mix. The variation range is between 0 and 100. The higher the value the higher the efficiency.

This is a measure of the qualitative result of a process.

Examples:

A) 61.00
B) 71.27
C) 46.80

The economic efficiency can be measured by the ratio:

$$\frac{\dfrac{\textit{unit production cost for the most valuable product}}{\textit{corresponding highest performance index}} - \dfrac{\textit{unit production cost for the less valuable product}}{\textit{corresponding lowest performance index}}}{\textit{weighted mean for the cost / performance index ratio of the product mix}} (100 - 0)$$

The lower the value the higher the efficiency. In cases where the value exceeds 100, one must consider 100, i.e. the lowest efficiency. This ratio represents the degree of correspondence between cost and performance for all the different products obtained, from the most to the least valuable.

Examples:

A) $$\frac{\dfrac{620\,(\$)}{65} - \dfrac{280\,(\$)}{52}}{\dfrac{407\,(\$)}{60.78}} = \frac{9.50 - 5.40}{6.70} = 61.10$$

B) $$\frac{\dfrac{21{,}000\ (\$)}{70} - \dfrac{7{,}800\ (\$)}{68}}{\dfrac{14{,}745\ (\$)}{71.27}} = \frac{3.00 - 1.15}{2.07} = 89.40$$

C) $$\frac{\dfrac{1{,}200\ (\$)}{45} - \dfrac{700\ (\$)}{40}}{\dfrac{893\ (\$)}{46.8}} = \frac{26.66 - 17.50}{19.08} = 48.00$$

Product Constant Quality Efficiency (PCQE)

The technical efficiency can be measured by means of the absolute sequential mean difference among the single values checked over a specific time period (usually a year); the ratio that must be considered is:

$$\frac{\underset{\substack{\textit{for the performance}\\ \textit{indices, over time, for}\\ \textit{all of the products or}\\ \textit{a representative}\\ \textit{statistical sample}}}{\textit{maximum detected interval}} - \underset{\dfrac{\Sigma|\Delta xdt|}{n-1}}{\textit{absolute sequential mean difference}}}{\substack{\textit{maximum detected interval for the performance}\\ \textit{indices, over time, for all of the products or}\\ \textit{a representative statistical sample}}} \quad (0-100)$$

Of course, this is done by calculating the weighted mean of the single values for the various products.

The higher the value the higher the efficiency.

This represents the degree of constancy of the products quality properties, over time.

Examples:

A) – maximum detected interval for the performance indices over time: 60.6 - 61.7
– absolute sequential mean difference: 0.3

$$\frac{1.1 - 0.3}{1.1} = 72.70$$

B) – maximum detected interval for the performance indices over time: 69.8 - 72.8
– absolute sequential mean difference: 1.0

$$\frac{3 - 1}{3} = 66.70$$

C) – maximum detected interval for the performance indices over time: 46.0 - 47.5
– absolute sequential mean difference: 0.3

$$\frac{1.5 - 0.3}{1.5} = 80.00$$

The economic efficiency can be measured by the ratio:

$$\frac{\textit{total costs for maintaining the highest constancy of quality properties}}{\textit{total increased commercial value of the products with high constancy of quality properties (obtained by increasing the sale price and/ or the quantity of the products to be sold)}} (100 - 0)$$

The lower the value the higher the efficiency.

If the costs for maintaing the highest constancy of quality properties exceeds the increased commercial value of the products, the ratio represents the highest inefficiency of this aspects, i.e. 100.

Examples:

A) $$\frac{1{,}628{,}200\ \$}{7{,}615{,}000} = 21.37$$

B) $$\frac{1{,}590{,}000{,}000\ \$}{3{,}810{,}000{,}000} = 41.73$$

C) $$\frac{17{,}500{,}000\ \$}{28{,}400{,}000} = 61.61$$

Equipment Static Operating Efficiency (ESOE)

The technical efficiency can be measured by means of the following formula:

$$\frac{\textit{total potential working time of the equipment (hours)} - \textit{total break time for set-up and other causes for the consolidated product mix (hours)}}{\textit{total potential working time of the equipment (hours)}} \quad (0 - 100)$$

Both working and break time of the equipment is measured by adding the working and break time for all types of process equipment. The higher the ratio the higher the efficiency.

This is a measure of the flexibility efficiency of the process, given a well defined product mix.

Examples:

A) $$\frac{60,000 - 18,000\,(hours)}{60,000} = 70.00$$

B) $$\frac{200,000 - 50,000\,(hours)}{200,000} = 75.00$$

C) $$\frac{45,000 - 15,000\,(hours)}{45,000} = 66.60$$

The economic efficiency can be calculated by the ratio:

$$\frac{\textit{additional amortization share due to breaks for set-up and other causes (maintenance) for the consolidated product mix}}{\textit{amortization share in the average unit production cost for the consolidated product mix}} \quad (100 - 0)$$

The lower the value the higher the efficiency.

Examples:

A) $$\frac{33.8\ (\$)}{101.7} = 33.24$$

B) $$\frac{2,105\ (\$)}{8,110} = 25.96$$

C) $$\frac{111.6\ (\$)}{330.4} = 33.78$$

Equipment Dynamic Operating Efficiency (EDOE)

Based on the aptitude of a process to modify the product mix by introducing new products (or articles within the same line of products) without modifying the process and the implemented technologies — except minor operational details — the technical efficiency can be measured by the ratio:

$$\frac{\begin{array}{c}\textit{total potential}\\ \textit{working time of}\\ \textit{the equipment (hours)}\end{array} - \begin{array}{c}\textit{total break time for set-up}\\ \textit{and other causes after}\\ \textit{the introduction of new products}\\ \textit{(or articles), without modifying the structure}\\ \textit{of the process (hours)}\end{array}}{\textit{total potential working time of the equipment (hours)}} \quad (0 - 100)$$

The higher the value the higher the efficency.

Examples:

A) $$\frac{60{,}000 - 12{,}000\ (\textit{hours})}{60{,}000} = 80.00$$

B) $$\frac{200{,}000 - 25{,}000\ (\textit{hours})}{200{,}000} = 87.50$$

C) $$\frac{45{,}000 - 8{,}000\ (\textit{hours})}{45{,}000} = 82.20$$

The economic efficiency can be calculated by the ratio:

$$\frac{\begin{array}{c}\textit{amortization share in the average}\\ \textit{unit production cost for the new product mix}\end{array}}{\begin{array}{c}\textit{amortization share in the average}\\ \textit{unit production cost for the consolidated product mix}\end{array}} \quad (100 - 0)$$

The lower the value the higher the economic efficiency.

Examples:

A) $\dfrac{75.6\ (\$)}{101.7} = 70.65$

B) $\dfrac{6{,}000\ (\$)}{8{,}110} = 74.00$

C) $\dfrac{198.8\ (\$)}{330.4} = 60.17$

Product Mix Variability Efficiency (PMVE)

The technical efficiency can be measured by the ratio:

$$\frac{\textit{number of new products (or articles) obtained by differently combining the inputs, without modifying the structure of the process}}{\textit{number of products (or articles) usually obtained in the process}} \quad (0 - 100)$$

The higher the value the higher the efficiency.

This is a measure of the real increase of the number of the products obtained by differently combining the inputs, of course without modifying the process.

Examples:

A) $\dfrac{5\ (n^\circ)}{10} = 50.00$

B) $\dfrac{35\ (n^\circ)}{63} = 55.50$

C) $\dfrac{2\ (n^\circ)}{4} = 50.00$

The economic efficiency can be calculated by the ratio:

$$\frac{\textit{average unit production cost for the new product mix obtained by differently combining the inputs, without modifying the structure of the process}}{\textit{average unit production cost for the consolidated product mix}} \quad (100 - 0)$$

The lower the value the higher the efficiency. If the average cost to produce the additional articles (or products) exceeds the cost to produce the consolidated product mix, the economic efficiency must be considered at the lowest level, i.e. 100.

Examples:

A) $$\frac{360\,(\$)}{407} = 88.45$$

B) $$\frac{12{,}500\,(\$)}{14{,}745} = 84.77$$

C) $$\frac{710\,(\$)}{893} = 79.50$$

Product Volume Efficiency (PVE)

The technical efficiency can be measured as:

$$\frac{\textit{quantity of products sold (by considering the product mix)}}{\textit{quantity of maximum producible products}} \quad (0 - 100)$$

The higher the value the higher the efficiency. This represents the degree of actual (commercial) utilization of the process equipment production potential (dimension).

Examples:

A) $$\frac{200{,}000\ \textit{(tons)}}{246{,}000} = 81.30$$

B) $$\frac{1{,}800{,}000\ (n^\circ\ of\ cars)}{2{,}250{,}000} = 80.00$$

C) $$\frac{280{,}000\ (tons)}{370{,}000} = 75.70$$

The economic efficiency can be calculated by means of the ratio:

$$\frac{\substack{maximum\ obtainable \\ products\ value} - \substack{actual\ sold \\ products\ value}}{maximum\ obtainable\ products\ value}\ (100\ -\ 0)$$

The lower the value the higher the efficiency.

Examples:

A) $$\frac{121{,}068{,}000\ -\ 97{,}692{,}000\ (\$)}{121{,}068{,}000} = 19.30$$

B) $$\frac{42{,}670{,}000{,}000\ -\ 34{,}300{,}000{,}000\ (\$)}{42{,}670{,}000{,}000} = 19.60$$

C) $$\frac{388{,}800{,}000\ -\ 317{,}000{,}000\ (\$)}{388{,}800{,}000} = 18.50$$

Input efficiency (IE)

The technical efficiency can be calculated by means of the ratio:

$$\frac{\substack{optimal\ total\ lead\text{-}time\ (hours\ or\ minutes) \\ per\ unit\ of\ product,\ after\ having\ optimized\ all \\ the\ inputs\ used\ in\ the\ various\ phases\ of\ the\ process}}{\substack{actual\ total\ lead\text{-}time\ (hours\ or\ minutes) \\ per\ unit\ of\ product,\ detected\ under\ normal \\ operating\ conditions}}\ (0\ -\ 100)$$

The higher the value the higher the efficiency.

This expresses the optimal performance of all inputs (equipment, labour, materials, energy), and, at the same time, the effectiveness of the process.

In cases of multiple production, the weighted mean of the single values must be calculated.

If the actual lead-time is lower than the minimum (theoretical), either the efficiency is considered 100 or the theoretical time must be recalculated.

The lowest (theoretical) lead-time of the equipment, or the highest (theoretical) quantity of products obtainable can be calculated by applying a method recently set up (Donini and Barbiroli, 1997), based on the linear programming method (Simplex).

The method needs the following data:

– technical constraints: minimum and maximum technical coefficients of each input which can be used in the various phases of the process; range of the lead-time for all equipment in each phase to get a unit quantity of product in the various different conditions (including waiting and transfer times between the various processing phases); range of the time for the various skills (executive, technical, intellectual, labour) directly and indirectly utilized; range of the various energy forms or sources (the quantities of materials are not included in the optimization process because they are virtually fixed inputs in each production phase and product);

– objective-function: optimal lead-time.

The Simplex Method, therefore, gives an optimal solution, expressed only in one measurement unit (it can also be expressed as quantity of product per unit of lead-time, again after having included and optimized all of the other inputs used in the phases of the process, and after having inverted the objective-function, that is: optional quantity of products).

The values to calculate the actual overall lead-time per unit of product or the actual quantity of product per unit of lead-time of all equipment can be detected during the running of the process.

In cases of product mix, the weighted mean of the different lead-time must be calculated.

Examples:

A) $$\frac{122\ (minutes)}{173} = 70.52$$

B) $$\frac{278.3\ (minutes)}{400.3} = 69.52$$

C) $$\frac{303.2\ (minutes)}{368.4} = 82.30$$

The economic efficiency can be calculated by the ratio:

$$\frac{\underset{cost}{actual\ unit\ production} - \underset{production\ cost}{optimal\,(minimum)\ unit}}{optimal\ (minimum)\ unit\ production\ cost}\ (100 - 0)$$

In cases of multiple production the values must be calculated as the weighted mean.

The optimal (minimum) unit production cost can be calculated by applying the linear programming method (Simplex) as for the technical efficiency, with the following data:

– economic constraints: minimum and maximum economic coefficients of each input which can be used in the various phases of the process; amortization share for the fixed capital that contributes to the final cost; unit cost for the various skills participating in the production; unit cost for materials and energy;
– objective-function: optimal production cost.

The actual production cost can be calculated by using the amounts of each input actually used in the process.

Examples:

A) $$\frac{407.0 - 330.7\ (\$ / ton)}{330.7} = 23.07$$

B) $$\frac{14{,}745 - 11{,}465\ (\$ / car)}{11{,}465} = 28.60$$

C) $$\frac{893 - 630\ (\$ / ton)}{630} = 41.74$$

The proposed indicators seem to be able to represent the manifold facets of technical and economic efficiency of a process and of its related technologies if one considers the most advanced features and requirements of each process.

As already highlighted in the introduction, some of the facets may be seen as crucial for the success or failure of the process itself, and, consequently, of the enterprise that manages the process and the products (i.e. input efficiency and effectiveness, flexibility and dimension efficiency), but some others may be considered as a linkage with the overall economic system (i.e. materials and energy efficiency; process, product and energy cycle environmental efficiency; quality efficiency).

As a matter of fact, there is no doubt that high materials and energy conversion efficiencies are important both for the economic competitiveness of the enterprise and for slowing down the depletion trends of natural resources, as well as high process and product environmental efficiencies contribute to increasing the credibility of the enterprise in the context of a total quality management, on the one hand, and to reduce the potential negative impacts of pollution and waste on the ecosystems, on the other.

In this sense, the twelve proposed indices, at technical and economic levels, make it possible to overcome the traditional boundaries of the enterprise and of specific production processes and they give a wider quantitative outlook of the techno-economic advantage of processes and technologies.

We must emphasize that the new method to measure the technical and economic efficiency of the inputs may be considered a way to improve the traditional indices to measure productivity, because it gives the values of the optimal processing time for the products (or the optimal amount of the products), but referred to all the used inputs, because they are jointly considered and combined together in an optimization process; in addition, measuring the distance between the optimal (theoretical) and the actual values gives further information about the overall techno-economic efficiency and effectiveness.

The reliability of the results obtained by applying these indices depends on the accuracy of the data; but all companies that want reliable information about the global performance of each process can easily arrange the collection and elaboration of the analytical data.

All of these indicators can be calculated in different conditions and processes so as to have comparable values, within the same company, in different periods of the year, in order to check the evolution of the efficiency/effectiveness of innovations, when implemented, or among dif-

TABLE 5.2. Data referred to a car manufacturing plant

	Type of obtained cars			
Required data for the elaboration of the various indicators	a	b	c	d
Relative importance of the various products (% of the quantities)	16.7	33.3	5.5	8.3
Relative importance of the various products (% of the value)	8.8	28.0	5.8	7.4
Total quantity of the original materials used for each product (tons)	350,000	780,000	139,000	216,000
Actual quantity of each product (n° of cars)	300,000	600,000	100,000	150,000
Cost for materials in each product ($)	772,000	2,250,000	434,000	585,000
Total production costs for each product ($)	2,340,000	7,500,000	1,550,000	1,950,000
Total quantity of energy introduced in the process (10^6MJ)				
Energy actually utilized in the process (10^6MJ)				
Cost for the original energy ($)				
Costs for managing and controlling the energy cycle ($)				
Quantity of original and intermediate materials and compounds not-transformed into products (tons)	50,000	180,000	39,000	66,000
Quantity of dissipatable materials and compounds used in the process not-released into the environment (tons)	40,000	160,000	31,000	58,000
Total costs for reducing the dissipative potential of the materials and compounds not-transformed into products ($)				
Quantity of materials present in the products (tons)	300,000	660,000	120,000	180,000
Quantity of non-dissipatable materials present in the products during and after use (tons)	210,000	462,000	84,000	126,000
Total costs for reducing the quantity of non-dissipatable materials into the environment ($)				
Theoretical (maximum) quantity of chemical and physical effluents producible in the energy cycle (10^9 tons)				
Actual quantity of the same effluents non-dissipatable (10^9 tons)				
Total costs for reducing the dissipative potential of the energy cycle ($)				

TABLE 5.2. Data referred to a car manufacturing plant (*continued*)

	Type of obtained cars				
Required data for the elaboration of the various indicators	e	f	g	Total	*W.M.
Relative importance of the various products (% of the quantities)	8.3	11.2	16.7	100.0	
Relative importance of the various products (% of the value)	10.9	14.6	24.5	100.0	
Total quantity of the original materials used for each product (tons)	236,000	304,000	487,000	2,512,000	
Actual quantity of each product (n° of cars)	150,000	200,000	300,000	1,800,000	
Cost for materials in each product ($)	886,000	1,080,000	1,953,000	7,960,000,000	
Total production costs for each product ($)	2,850,000	4,000,000	6,300,000	26,540,000,000	
Total quantity of energy introduced in the process (10^6MJ)				2,700	
Energy actually utilized in the process (10^6MJ)				2,000	
Cost for the original energy ($)				3,980,000,000	
Costs for managing and controlling the energy cycle ($)				600,000,000	
Quantity of original and intermediate materials and compounds not-transformed into products (tons)	86,000	104,000	187,000	712,000	
Quantity of dissipatable materials and compounds used in the process not-released into the environment (tons)	78,000	90,000	167,000	624,000	
Total costs for reducing the dissipative potential of the materials and compounds not-transformed into products ($)				1,857,000,000	
Quantity of materials present in the products (tons)	200,000	260,000	420,000	2,140,000	
Quantity of non-dissipatable materials present in the products during and after use (tons)	140,000	182,000	294,000	1,498,000	
Total costs for reducing the quantity of non-dissipatable materials into the environment ($)				1,327,000,000	
Theoretical (maximum) quantity of chemical and physical effluents producible in the energy cycle (10^9 tons)				25	
Actual quantity of the same effluents non-dissipatable (10^9 tons)				10	
Total costs for reducing the dissipative potential of the energy cycle ($)				265,400,000	

TABLE 5.2. Data referred to a car manufacturing plant (*continued*)

	Type of obtained cars			
Required data for the elaboration of the various indicators	a	b	c	d
Global Performance Indices	68	75	72	62
Maximum interval detected for the performance indices over time	67-69	73-77	71-74	60-64
Total costs for maintaining the constancy of quality ($)				
Total increased commercial value of the products with high constancy of quality properties ($)				
Total potential working time of the equipment (hours per year)				
Total break time for set-up and other causes (hours per year)				
Additional amortization share in the unit production cost due to breaks ($)				
Real break time for set-up and other causes after the introduction of new products (hours per year)				
Amortization share in the unit production cost for the consolidated mix ($/car)				
Amortization share in the unit production cost for the new product mix ($/car)				
Unit production cost for the new product mix ($/car)				
Quantity of products sold on a yearly basis (cars)	300,000	600,000	100,000	150,000
Maximum quantity of obtainable products (cars)	400,000	700,000	140,000	200,000
Actual sold product value ($)	3,000,000	9,600,000	2,000,000	2,550,000
Unit price obtained for each product sold ($/car)	10,000	16,000	20,000	17,000
Maximum obtainable value of the products ($)	4,000,000,000	11,200,000,000	2,800,000,000	3,400,000,000
Optimal lead-time per unit of product (minutes)	240	280	300	350
Actual lead-time per unit of product (minutes)	330	330	440	510
Actual unit production cost ($/car)	7,800	12,500	15,500	13,000
Optimal unit production cost ($/car)	5,700	10,600	10,080	9,100
Number of products usually produced in the process				
Number of new products obtained without modifying the process				

TABLE 5.2. Data referred to a car manufacturing plant (*continued*)

	Type of obtained cars				
Required data for the elaboration of the various indicators	e	f	g	Total	*W.M.
Global Performance Indices	76	70	70		71.27
Maximum interval detected for the performance indices over time	74-77	69-71	69-71		69.8-72.8
Total costs for maintaining the constancy of quality ($)				1,590,000,000	
Total increased commercial value of the products with high constancy of quality properties ($)				3,810,000,000t	
Total potential working time of the equipment (hours per year)				200,000	
Total break time for set-up and other causes (hours per year)				50,000	
Additional amortization share in the unit production cost due to breaks ($)					2,105
Real break time for set-up and other causes after the introduction of new products (hours per year)				25,000	
Amortization share in the unit production cost for the consolidated mix ($/car)					8,110
Amortization share in the unit production cost for the new product mix ($/car)					6,000
Unit production cost for the new product mix ($/car)					12,500
Quantity of products sold on a yearly basis (cars)	150,000	200,000	300,000	1,800,000	
Maximum quantity of obtainable products (cars)	200,000	270,000	340,000	2,250,000	
Actual sold product value ($)	3,750,000	5,000,000	8,400,000	34,300,000,000	
Unit price obtained for each product sold ($/car)	25,000	25,000	28,000		
Maximum obtainable value of the products ($)	5,000,000,000	6,750,000,000	9,520,000,000	42,670,000,000	
Optimal lead-time per unit of product (minutes)	310	380	320		278.3
Actual lead-time per unit of product (minutes)	460	540	350		400.3
Actual unit production cost ($/car)	19,000	20,000	21,000		14,745
Optimal unit production cost ($/car)	13,300	14,000	18,900		11,465
Number of products usually produced in the process				7x9=63	
Number of new products obtained without modifying the process				7x5=35	

* W.M.= Weighted Mean

TABLE 5.3. Data referred to the production of polymers in a chemical plant

	Type of obtained polymers					
Required data for the elaboration of the various indicators	a	b	c	d	Total	*W.M.
Relative importance of the various products (% of the quantity)	14.3	21.4	28.6	35.7	100.0	
Relative importance of the various products (% of the value)	19.2	24.0	28.8	28.0	100.0	
Total quantity of the original materials used for each product (tons)	66,000	81,000	104,000	118,000	369,000	
Actual quantity of each product obtained (tons)	40,000	60,000	80,000	100,000	280,000	
Cost for materials in each product ($)	13,440,000	17,400,000	21,600,000	18,900,000	71,340,000	
Total production costs for each product ($)	48,000,000	60,000,000	72,000,000	70,000,000	250,000,000	
Total quantity of energy introduced in the process (10^6MJ)					3,300	
Energy actually utilized in the process (10^6MJ)					2,050	
Cost for the original energy ($)					45,000,000	
Costs for managing and controlling the energy cycle ($)					2,000,000	
Quantity of original and intermediate materials and compounds not-transformed into products (tons)	26,000	21,000	24,000	18,000	89,000	
Quantity of dissipatable materials and compounds used in the process not-released into the environment (tons)	19,000	15,000	20,000	12,000	66,000	
Total costs for reducing the dissipative potential of the materials and compounds not-transformed into products ($)	3,800,000	5,400,000	6,300,000	8,000,000	22,500,000	
Quantity of materials present in the products (tons)	40,000	60,000	80,000	100,000	280,000	
Quantity of non-dissipatable materials present in the products (tons)	30,000	45,000	70,000	100,000	245,000	
Total costs for reducing the quantity of non-dissipatable materials into the environment ($)					17,500,000	
Theoretical (maximum) quantity of chemical and physical effluents producible in the energy cycle (10^6 tons)					12	
Actual quantity of the same effluents non-dissipatable (10^6 tons)					4	
Total costs for reducing the dissipative potential of the energy cycle ($)					10,000,000	

TABLE 5.3. Data referred to the production of polymers in a chemical plant (*continued*)

	Type of obtained polymers					
Required data for the elaboration of the various indicators	a	b	c	d	Total	*W.M.
Global Performance Indices	45	55	50	40		46.8
Maximum interval detected for the performance indices over time	44.1-45.9	54.3-55.7	49.2-50.8	39.3-40.7		46.0-47.5
Total costs for maintaining the constancy of quality ($)					17,500,000	
Total increased commercial value of the products with high costancy of quality properties ($)					28,400,000	
Total potential working time of the equipment (hours per year)					45,000	
Total break time for set-up and other causes (hours per year)					15,000	
Additional amortization share in the unit prduction cost due to breaks ($)						111.6
Real break time for set-up and other causes after the introduction of new products (hours per year)					8,000	
Amortization share in the unit production cost for the consolidated product mix ($/ton)						330.4
Amortization share in the unit production cost for the new product mix ($/ton)						198.8
Unit production cost for the new product mix ($/ton)						710
Quantity of products sold on a yearly basis (tons)	40,000	60,000	80,000	100,000	280,000	
Maximum quantity of producible products (tons)	52,000	78,000	105,000	135,000	370,000	
Actual sold product value ($ per year)	60,000,000	75,000,000	92,000,000	90,000,000	317,000,000	
Unit price obtained for each product sold ($/ton)	1,500	1,250	1,150	900		
Maximum obtainable value of the products ($)	78,000,000	97,500,000	94,500,000	118,800,000	388,800,000	
Optimal lead-time per unit of product (minutes)	110	160	140	90		122
Actual lead-time per unit of product (minutes)	145	235	195	130		173
Actual unit production cost ($/ton)	1,200	1,000	900	700		893
Optimal unit production cost ($/ton)	900	700	630	480		630
Number of products usually produced in the process					4	
Number of new products obtained without modifying the process					2	

* W.M.= Weighted Mean

TABLE 5.4. Summary of the values obtained by calculating the proposed efficiency Indicators by considering three actual cases

	Iron-Steel Making		*Car Manufacturing*		*Polymers Production*	
Type of Efficiency	Technical Efficiency	Economic Efficiency	Technical Efficiency	Economic Efficiency	Technical Efficiency	Economic Efficiency
1) Materials Cycle Efficiency (MCE)	60.42	64.46	85.20	18.79	75.88	34.49
2) Energy Cycle Efficiency (ECE)	47.60	100.00	74.00	55.50	62.10	68.19
3) Process Overall Evironmental Efficiency (POEE)	55.00	23.74	87.60	23.78	74.10	41.56
4) Final Product Evironmental Efficiency (FPEE)	100.00	0.00	70.00	19.57	87.50	32.32
5) Energy Cycle Evironmental Efficiency (ECEE)	20.00	52.51	40.00	9.01	33.30	35.78
6) Product Absolute Quality Efficiency (PAQE)	61.00	61.10	71.27	89.40	46.80	48.00
7) Product Constant Quality Efficiency (PCQE)	72.70	21.37	66.70	41.73	80.00	61.61
8) Equipment Static Operating Efficiency (ESOE)	70.00	33.24	75.00	25.96	66.60	33.78
9) Equipment Dynamic Operating Efficiency (EDOE)	80.00	70.65	87.50	74.00	82.20	60.17
10)Product Mix Variability Efficiency (PMVE)	50.00	88.45	55.50	84.77	50.00	79.50
11)Product Volume Efficiency (PVE)	81.30	19.30	80.00	19.60	75.70	18.50
12)Input Efficiency (IE)	70.52	23.07	69.52	28.60	82.30	41.74
Overall Efficiency	768.54	557.89	862.29	490.71	816.48	555.64

ferent production processes and technologies, in different companies, at the same moment.

If one considers the several facets of efficiency at the same level of importance, the values can be simply summed up, as has been done for the three actual cases considered and shown in Table 5.4.

5.2. PRODUCTIVITY AND FLEXIBILITY

The fundamental problem with designing and managing manufacturing systems is the trade-off that exists between flexibility and productivity.

According to traditional logic, high flexibility penalizes productivity; vice-versa, high productivity penalizes flexibility (Bonel, 1984; Silvestrelli, 1984; Gustavsson, 1985).

For several decades, processes were applied in the manufacturing industry aimed at saving factors and at efficiency; this aim was achieved by sacrificing flexibility to economy of scale. This led to increased production specialization which, by restricting the field of skills and efforts required by a specific task, made it possible to apply a more intense mechanization and, at the more highly-evolved stage (such as today), of automation.

Thus the specialization of tasks makes it possible to automate production, with significant effects on the attainable volumes. The productivity of factors and the entire process can therefore achieve potentially high levels. "Potentially", because more specialized plants, whether in-line or continuous-flow, must run at full capacity, meaning they must have high utilization; otherwise the inactivity of the process leads to efficiency losses that wipe out for what has been gained in productivity.

If the company is unable to achieve high sales volumes for standardized products, it is convenient to opt for systems more compatible with a limited scale of production.

The degree of flexibility and productivity in a system is determined by the features of the product in terms of standardization/differentiation and high/low volumes.

If the market is unstable and/or extremely segmented, the company that wishes to satisfy the entire range of needs or at least follow its evolution must be fitted out with decidedly flexible organization and manufacturing conditions. It must therefore produce small-medium quantities of a certain number of models, and thus the objective of maximizing economies of scale, typical of continuous processes, loses its significance.

In the late '70s large companies found themselves facing what Abernathy has defined as "the productivity dilemma" (1978): to choose flexibility, sacrificing productivity, or to choose productivity but render its manufacturing structures more rigid. Throughout the 1970s, American companies were indeed unable to sustain industrial productivity, the rates of which fell conspicuously, and they intervened in the organizational structure only in order to achieve flexibility. In short, traditional technology was maintained and the work force was depended upon to provide all of the flexibility necessary in order to react to the "turbulent environment" (Marchisio, 1984). This solution was found to be insufficient, and the productivity–flexibility trade-

off was not reduced. Only in the latter half of the decade did they begin to understand — also thanks to the efforts of the Japanese — that without destructured and flexible technology it was impossible to sustain for long a manufacturing process suited to a variable (segmented) market.

In the '80s, synergically correlated structural, organizational and technological solutions allowed continuous processes to regain a certain degree of flexibility, while maintaining high flexibility; and batch processes — traditionally flexible, but inefficient — achieved higher yields.

The flexibility made possible by more recent technology (flexible automation) allows us to foresee that, over time, much of the so-called "hard automation" will acquire greater flexibility, and thus the dividing line between automated systems used in semi-continuous production lines and those used for batch production is becoming less marked. The possibility of combining the flexibility of small-batch production lines with mass production techniques should have important consequences on productivity over the next two decades (Alberghini, 1987; Riggs and Felix, 1983).

To summarize the above analysis, two basic characteristics may be identified in the environment companies operate in today (Sciarelli, 1985):

- environmental turbulence requires more flexible structures and organizational models, that can be quickly adapted to changing conditions outside the company;
- market conditions (increased competitive pressure) require improved productivity. Companies must therefore seek out and take advantage of every opportunity to reduce costs.

The problem facing companies is therefore to innovate towards flexibility without suffering from reduced productivity, impossible to sustain in competitive terms.

To focus more clearly on this problem we must point out that the flexibility of a manufacturing system develops in three dimensions:

- technological dimension (in the broad sense): number of possible states;
- economic dimension: cost of adaptability;
- time dimension: time for adaptability.

The flexibility cost of a system may be understood to mean:

1) the cost of the change in and of itself;

2) the cost to be sustained in order to make the system open to changes.

Actually, the first cost is directly related to flexibility; the second, while it is one of the most important factors to be analyzed when a company begins studying the convenience of adopting a flexible manufacturing system, is

not directly related to flexibility itself.

The cost and time of flexibility are clearly correlated. Not only is cost often a consequence of the time necessary in order to make a status change, but their mutual relationship goes much further: the time necessary in order to change from one status to another may be reduced by sustaining higher costs, and similarly the cost of a certain variation may be reduced by making the change over a longer period of time.

It is obvious that cost and time are good indicators of the difficulties encountered when making a change; at the same time, they represent the limits beyond which the flexibility of a system ceases to be such, becoming simply a conversion-restructuring of the system itself.

If, hypothetically speaking, the limitations of time and cost were eliminated, all variations would become at least theoretically possible, including a total change in the manufacturing system. But this is not a realistic hypothesis; therefore, there is a need to establish a boundary between system flexibility and system change.

This boundary is arbitrary, but Slack rightly believes that flexibility, in general, implies the ability to change the operations carried out by a system by making simply small changes in its physical equipment (1984).

Now, we should emphasize the fact that manufacturing systems are heavily dependent on the product. It is indeed possible to establish a corresponding relationship between product and process, based not only on the characteristics of the product but also the dynamics to which they are subjected due to the effects of the evolution of the product's life cycle. Below we shall illustrate a model that outlines the product/process relationship on a two-dimensional matrix, indicating the degree of standardization of the product and the degree of rigidity/flexibility of the manufacturing process, respectively.

The characteristics that most affect the choice of manufacturing system are:

– the variety of models requested by users;

– the production volume.

Basically, the company may deal with a standardized product, with high sales volumes and planned production; or, in the opposite situation, it may have to create a custom-made product or one with various models, with low volumes for each model, and manufactured upon order. Between these two extreme cases, there exists a full range of intermediate situations, each of which requires the adoption of an "ad hoc" manufacturing system.

The important consideration that emerges from what we have said thus far

is that the marketing policy of the company conditions its manufacturing policy as well, determining the level of productivity and flexibility that may be achieved in production.

The consequence of this is that in making marketing choices the business must take into account not only the connections between the product and process, but must jointly analyze the relationships between market, product and process (Hill, 1987).

The conception according to which the manufacturing structure must be efficient above all else is misleading, in that the manufacturing system is a sub-system of the larger company system. It is therefore not simply a matter of maximizing the efficiency of the production "sub-system", but most of the strategic positioning of the company system in the sector in which it operates.

Numerous objectives to be achieved can be traced back to the production function, and may be interpreted as functions of competitiveness (Schmenner, 1987): minimizing production costs, maximizing quality and performance, customizing the product, reducing lead times, increasing volume elasticity, flexibility of the mix, etc.

Some of these objectives are obviously incompatible with one another. A manufacturing system cannot compete along all competitive dimensions with equal intensity. Thus the company must choose the priority objective, which must stem from the overall strategic aims of the company itself (Skinner, 1982).

In this regard, Skinner speaks of "focusing" the manufacturing system: that is, the system must be focused on the objective considered to be top priority, rather than pursue different criteria of competitiveness by adopting various types of compromises, which reduce its effectiveness (Skinner, 1974).

5.3. CONDITIONS FOR RECONCILING PRODUCTIVITY AND FLEXIBILITY

If we consider the flexibility of a system according to its two most easily known aspects, ability to produce various products over the same period (product mix flexibility) and ability to innovate the articles manufactured over time, according to the changing needs of demand (flexibility in producing new articles), we can immediately identify three main elements that affect this flexibility (and, inversely, productivity): the type of manufacturing process adopted, the degree of specialization of the systems and their layout

(Brugger, 1975; Woodward, 1965; Moore, 1984; Brandolese, Brugger, et al., 1985). These elements are strictly interdependent, in the sense that to adopt a certain type of process implies adopting, within a certain range of variability, a certain degree of specialization of the systems and a certain layout within the plant. In particular, product mix flexibility may be attained only by using systems that are prepared in order to carry out simultaneously a variety of manufacturing processes. This flexibility is indeed incompatible with "continuous" type manufacturing processes (in themselves highly productive), given the technical and organizational impossibility of carrying out simultaneous productions with the same systems. The decision to create technical manufacturing units with such flexibility thus largely depends on the marketing policy, and more specifically on the product policy, that the company intends to carry out: manufacturing units of this type will indeed be necessary for all of those companies which, using a single industrial plant, tend to make a "variety of products" or carry out a "diversified production" policy. Thus, in order to achieve mix flexibility it is necessary to adopt an intermittent (or multicycle) process. If the plant carries out the individual conversions in a required sequence, intermittence is achieved by varying the running conditions of the plant itself, and thus batches of different products alternate for limited periods. When instead the plant consists of disjointed groups of machines, each of which can carry out a variety of cycles regardless of the status of the other machines, we have a situation in which product variety can be achieved by adopting mixes of different processes.

The plant layout is closely related to the type of process chosen. Continuous processes are based on the product-flow layout, in which the machines and labour are specialized (single-purpose), a single cycle is used, handling is reduced, rates are accelerated and storage is limited. In short, productivity is very high, but so is the rigidity: the system is heavily penalized if changes are made to the products, quality, quantity.

Intermittent processes are instead based on broken lines or process layout, in which the machines are multipurpose and arranged according to departments rather than the sequence of the cycle, they are used for many cycles and many products, rates are slower, costs are borne for storing the stock that results from the alternation of cycles, materials transit is high: here, productivity is rather low, but the flexibility is considerable.

The more a company uses special machines to create a given production, the more difficult it will be to adapt it to quality changes in the products. On the other hand, the specialization of machines increases the productivity of

the process, since it makes it possible to apply "custom-made" technologies for a given product.

In conclusion, it is important to identify the direction to take with the purpose of increasing the flexibility without drastically reducing the productivity of the system.

The basic lines of intervention in the technical-production area are as follows:

1) on the product;
2) on production organization;
3) on production scheduling;
4) on process technology;
5) on the system of company-to-company relationships.

Thus to make a production flexible involves not only specific intervention in the technical area (strictly speaking), as is often believed, but involves the operating procedures of the entire company. It is a series of complex and involved interventions whose elements are logically connected to one another in an organic and non-random strategic design.

The lines of intervention mentioned may be considered as conditions for reconciling productivity and flexibility.

The first condition is to modularize design and production, with the related standardization of the individual stages of the operating cycle.

Standardization is a necessary condition of specialization, since it requires repetitiveness, but also leads to rigidity in product supply. This rigidity may be reduced — in some cases considerably — if the numerous variations to be made in the product in order to better meet the differentiation needs of the market are conceived right from the design stage, as the result of combining a series of standardized parts common to all of the variations. So in confluent-type processes, when producing standardized individual components (modules), it is possible to achieve the high levels of productivity typical of repetitive, standardized processes; during assembly, instead, the flexibility necessary to provide the numerous product variations is acquired, the demand for which is typical of mature, unstable markets. Computer aided design (CAD) is an effective instrument for adopting this type of design for product ranges with numerous variations and consisting of a wide variety of components.

The second condition is segmentation of the linearity of the manufacturing cycle.

Indeed, flexibility can be achieved from an organizational standpoint by

making the various processing units more independent, from plants to stages to individual operations; thus by breaking down the continuity and integration of the cycle (Gustavsson, 1985).

The greater need for co-ordination that derives from this is satisfied by a more intensive use of computer science. Thus large systems are broken down into small, specialized and independent sub-units. This makes it possible to extricate tasks otherwise compressed within the rigid procedures of repetitive cycles.

This concept has been practically applied, at the company level, by decentralized manufacturing (fifth condition identified) and, at the plant level, by adopting a cell layout and group technology.

Decentralized manufacturing is a further initiative aimed at reducing the rigidity of the structure.

Recourse to sub-contractors increases flexibility considerably. Companies are thus pushed to limit the degree of vertical integration to those processes for which the company offers a specific superiority, in which they specialize. Those phases not carried out internally are hired out: sub-contracting relationships are set up with small- and medium-size-companies highly specialized in manufacturing specific component parts for others, or hires out the processing alone (contract processing). This solution considerably softens the negative effects of demand instability and, more generally, environmental turbulence.

The third condition identified concerns changes in the system of production scheduling. From the use of "material requirement planning", we now apply "just-in-time production", with significant consequences on the entire business-system.

Finally, the fourth condition implies the need to adopt the most recent results of technological progress, consisting of programmable automation and flexible automation. New standardized techniques are adopted in intermittent processes for retooling machines, to reduce flow conversion times and costs. A decisive contribution towards greater adaptability is provided by the introduction of computerized numerical control (CNC) and direct numerical control machines (DNC).

Groups of a series of such machines, linked by means of multipurpose robots and other conveyor systems, create flexible manufacturing systems (FMS) which can continuously produce several variations on products, even in random succession, with pre-set composition percentages.

Chapter 6

TECHNOLOGICAL DYNAMICS AND QUALITY ISSUES

6.1. THE MULTIPLE DIMENSIONS OF QUALITY

The quality of goods — which is the decisive element for using and, therefore, assessing them — has various definitions according to the approach taken:

transcendent: condition of innate and absolute excellence of the attributes

product standpoint: the entity of non-monetizable attributes in each unit of monetizable attributes.

user standpoint: the ability to satisfy needs

manufacturer standpoint: the degree to which a product conforms with the required design and specifications

value standpoint: the degree of excellence of the attributes with respect to the price.

Each of these definitions has its own validity and diverse implications in the economic situation; at times they are in contrast with one another.

However, regardless of the standpoint of the various definitions, product quality appears through a number of attributes, which may be grouped into the following eight categories according to the different dimension:

- Performance
- Features
- Reliability
- Conformance
- Durability
- Serviceability
- Aesthetics
- Perceived quality

Each category is self-contained and distinct, for a product or service can be ranked high on one dimension while being low on another. However, in many cases the dimensions are interrelated. Sometimes an improvement in one may be achieved only at the expense of another; at other times two di-

mensions, like reliability and conformance, may move together. The interrelationships suggest the framework's relevance to strategic quality management (Morgan, 1985; Garvin, 1988).

Performance. First on the list of dimensions is performance, which refers to the primary operating characteristics of a product. For an automobile, they would be traits like acceleration, handling, cruising speed, and comfort; for a television set, they would include sound and picture clarity, colour, and the ability to receive distant stations. In service businesses such as fast foods and airlines, an important aspect of performance is often service speed or the absence of waiting time.

This dimension of quality combines elements of both the product-based and user-based approaches. Measurable product and service attributes are involved, and brands can usually be ranked objectively on at least one dimension of performance. Overall performance rankings, however, are more difficult to develop, especially when they involve benefits that lack universal appeal. Then specific applications must be examined, for products cannot be compared in the abstract.

The connection between performance and quality is equally dependent on circumstances. Whether performance differences are perceived as quality differences normally depends on individual preferences.

Features. Features are those primary and secondary characteristics that supplement the product's basic functioning. Primary features, like product performance, involve objective and measurable attributes; secondary features involve subjective, and often non measurable, attributes. The distinction between the two is largely a matter of centrality or degree of importance to the user. In many cases, the line separating primary product characteristics (performance) from secondary characteristics (features) is difficult to draw.

Reliability. Reliability reflects the probability of a product's malfunctioning or failing within a specific period of time. Among the most common measures of reliability are the mean time to first failure, the mean time between failures, and the failure rate per unit time. Because these measures require a product to be in use for some period, they are more relevant to durable goods than to products and services that are consumed instantly.

Reliability normally becomes more important to consumers as downtime

and maintenance become more expensive. Recent market research shows that reliability has become an automobile's most desired attribute.

Conformance. A related dimension of quality is conformance, or the degree to which a product's design and operating characteristics meet pre-established standards. The main approach to conformance equates conformance with meeting specifications. All products and services involve specifications of some sort. When new designs or models are developed, dimensional standards must first be set for parts, and purity requirements for materials. These specifications are seldom defined as a single value. Normally, they include a target or centring dimension, as well as a permissible range of variation or tolerance.

This view of conformance is closely associated with process control and sampling technique. Specification limits are matched against the inherent capabilities of a manufacturing process — the greatest precision and least variability that it is capable of producing under controlled operating conditions — and the process is centred as well as possible, ensuring that the majority of parts produced will comply with the specific limits.

Both reliability and conformance are closely tied to the manufacturing-based approach to quality. Improvements in both measures normally translate directly into quality gains, because defects, field failures and processing errors are regarded as undesirable by virtually all consumers (Garvin, 1988).

Durability. Durability, a measure of product life, has both economic and technical dimensions. Technically, durability can be defined as the amount of use one gets from a product before it physically deteriorates.

Durability becomes more difficult to interpret when repair is possible. Then the concept takes on an added dimension, for product life will vary with changing tastes and economic conditions. Each time a product fails, they must weigh up the expected cost, in both money value and personal inconvenience, of future repairs against the investment and operating expenses of a newer, more reliable model. In such circumstances, product life is determined by repair costs, personal valuations of time and inconvenience, changing fashions, losses due to downtime, and relative prices as much as it is by the quality of components or materials.

This approach to durability has two important implications. First, it suggests that durability and reliability are closely linked. Second, an increase in product life may not be due to technical improvements or to the use of

longer-life materials; the underlying economic environment may simply have changed.

Yet when assessments are made at a single point in time and comparable levels of maintenance are assumed, durability still varies widely among brands. In 1981, for example, estimated product lives for major US home appliances ranged from 9.9 years (Westinghouse) to 13.2 years (Frigidaire) for refrigerators, 5.8 years (Gibson) to 18.0 years (Maytag) for washers, 6.6 years (Wards) to 13.5 years (Maytag) for dryers, and 6.0 years (Sears) to 17.9 years (Kirby) for vacuum cleaners. Such wide range suggests that durability is a potentially fertile area for further quality differentiation.

Serviceability. A further important dimension of quality is serviceability, or the speed, competence, and ease of repair. Consumers are concerned not only about product breakdowns but also about the elapsed time before service is restored and the frequency with which service calls or repairs fail to correct outstanding problems.

Some of these variables can be measured quite objectively, others reflect differing personal standards of what constitutes acceptable service. Responsiveness is typically measured by the mean time to repair. Since a faster repair can be related to higher quality and low costs, serviceability is increasing its importance in all consmers' choices.

Aesthetics. This dimension of quality is the most subjective. Aesthetics — how a product looks, feels, sounds, tastes or smells — is clearly a matter of personal judgement and a reflection of individual preferences. In fact, the marketing concept of "ideal points" has often been applied to just this dimension of quality.

Perceived Quality. Consumers do not always possess complete information about a product or a service's attributes. Frequently, indirect measures are the only basis for comparing brands. Images, advertising, and brand names — perceptions of quality rather than the reality itself — can be crucial. Recently, market research has found the country of manufacture of a product is viewed by many consumers as an indication of its quality (Morgan, 1985).

Reputation is also one of the primary contributors to perceived quality, and it comes from an unstated analogy: that the quality of products manufactured in earlier periods, or the quality of goods in a newly developed

product line is similar to the quality of a company's more established products. In the early years of a new product — especially a capital good, whose reliability and durability may take years to demonstrate — consumers often have little other information on which to base their purchases.

6.2. THE EVOLUTION OF QUALITY APPROACHES

Approaches to quality have evolved through several phases, over the last century: inspection (up to 1930), statistical quality control (1931–1950), quality assurance (1951–1980), strategic quality management (from 1985).

The *inspection era* was characterized by the target of product uniformity, quality was regarded as an independent function with a separate management responsibility, and quality control was limited to inspection (Radford, 1992).

The *statistical control era* was based on the Shewhart definition of quality, in terms of product-based, manufacturing-based and user-based definitions, and required that numbers derived from measures of products or processes be analyzed according to a theory of variation that links outcomes to uses (Shewhart, 1931); this means that the nonconforming items produced by a manufacturing process can be studied statistically, for determining the range of acceptable variation for each property/performance, of products. Of course, the statistical variability of products' quality should be investigated, as it has been done for foodstuffs (Barbiroli and Scardovi, 1963; Barbiroli, 1964 and 1969).

After the Second World War, some of the significant developments in the evolution of quality were achieved in Japan (Ishikawa, 1987) and United States (Juran, 1951; Deming, 1986; Feigenbaum, 1983); while Japanese business leaders focused their attention on the causes and not just the results, developing the cause/effect diagram, the Americans devoted their efforts to identifying acceptable quality levels, which would lead to establishing the level of acceptable defects, without encouraging continuous improvement. For more information on quality control methods, the work of Larrien (1963), Duncan (1965), Besterfield (1986), Ishikawa (1987), Robertson (1989), Taylor (1989) can be examined.

During the *quality assurance era* the concept of quality in the United States evolved from a narrow, manufacturing-based discipline to one with implications for management. Statistics and manufacturing control re-

mained important, but coordination with other areas such as design, engineering, planning and service activities also became important to quality. While quality remained focused on defect prevention, the assurance era brought a more proactive approach and some new tools (Barkman, 1989).

Four have been the elements of quality assurance: quantifying the costs of quality, total quality control, reliability engineering and zero defects.

Until the 1950s, managers assumed it was important to improve quality because defects were expensive, but they had no idea about the entity and they had no tool for measuring the costs of quality (Campanella and Corcoran, 1987).

Juran (1951) divided the costs of achieving a given level of quality into *avoidable costs* and *unavoidable costs*. *Unavoidable costs* are those related to defect prevention, for inspection, sampling, sorting and other quality control activities; *avoidable costs* are those related to defects and product failures, including scrapped materials, labour time for rework and repair, complaint processing, and financial losses for reduced sales.

In addition, understanding and analyzing the costs of quality help better understand the manufacturing process (Fine, 1986).

Total quality control was based on the principle that, to provide high effectiveness, quality control must start at the design stage of the product and end only when the product has been placed in the hands of the customer.

To make total quality control work, many companies developed matrices or relationship charts, which defined the areas of responsibility and the cross-functional tasks.

The areas of responsibility usually were:
– establish quality level for business
– establish product design specifications
– establish manufacturing process design
– produce products to design specifications
– determine process capabilities
– qualify suppliers on quality
– plan the quality system
– plan inspection and test procedures
– design test and inspection equipment
– feed back quality information
– gather complaint data
– analyze complaint data
– obtain corrective action

– compile quality costs
– analyze quality costs
– in-process quality measurements
– in-process quality audit
– final product inspection.

Despite the emphasis on teamwork, the total quality control matrix suggests that more than half of the primary responsibilities for quality belong to the quality control department, which is anthitetical to modern Total Quality Management.

While total quality control was emerging, *reliability engineering* was developing, with an even greater reliance on probability theory and statistics. Engineers developed mathematical models for predicting equipment performance over time, under different operating conditions, and a variety of techniques to improve reliability and reduce failure rates; these included failure mode and effect analysis, individual component analysis, derating, redundancy, monitoring of field failures.

Both total quality control and reliability engineering aimed to prevent defects and emphasized engineering skills and attention to quality through the design process; by contrast, zero defects focused or management expectations and human relations.

Rather than rely on massive inspection to achieve high quality, zero defects programmes offered workers incentives to lower defect rates.

The *quality assurance era* expanded the involvement of all company functions and prompted to actively pursue perfection; however, the approaches to achieving quality still remained largely defensive, e. g. controlling quality still meant acting on defects. Only during the '70s did managers start to be aware that quality had a strategic importance in managing a company.

The *strategic quality management era* leads managers to see the links between losses of profitability and poor quality, and to realize that producing products with high quality and lower cost would lead to gain market shares and increase profitability. This view of quality incorporates elements of each of the preceding eras, but quality is considered an opportunity for a competitive advantage.

Total quality management is the set of elements of managerial culture which permits — through a systemic-integrated approach — to pursue customer satisfaction. In this sense, total quality is seen as the group of individual features present in all stages and areas of an activity, from design to

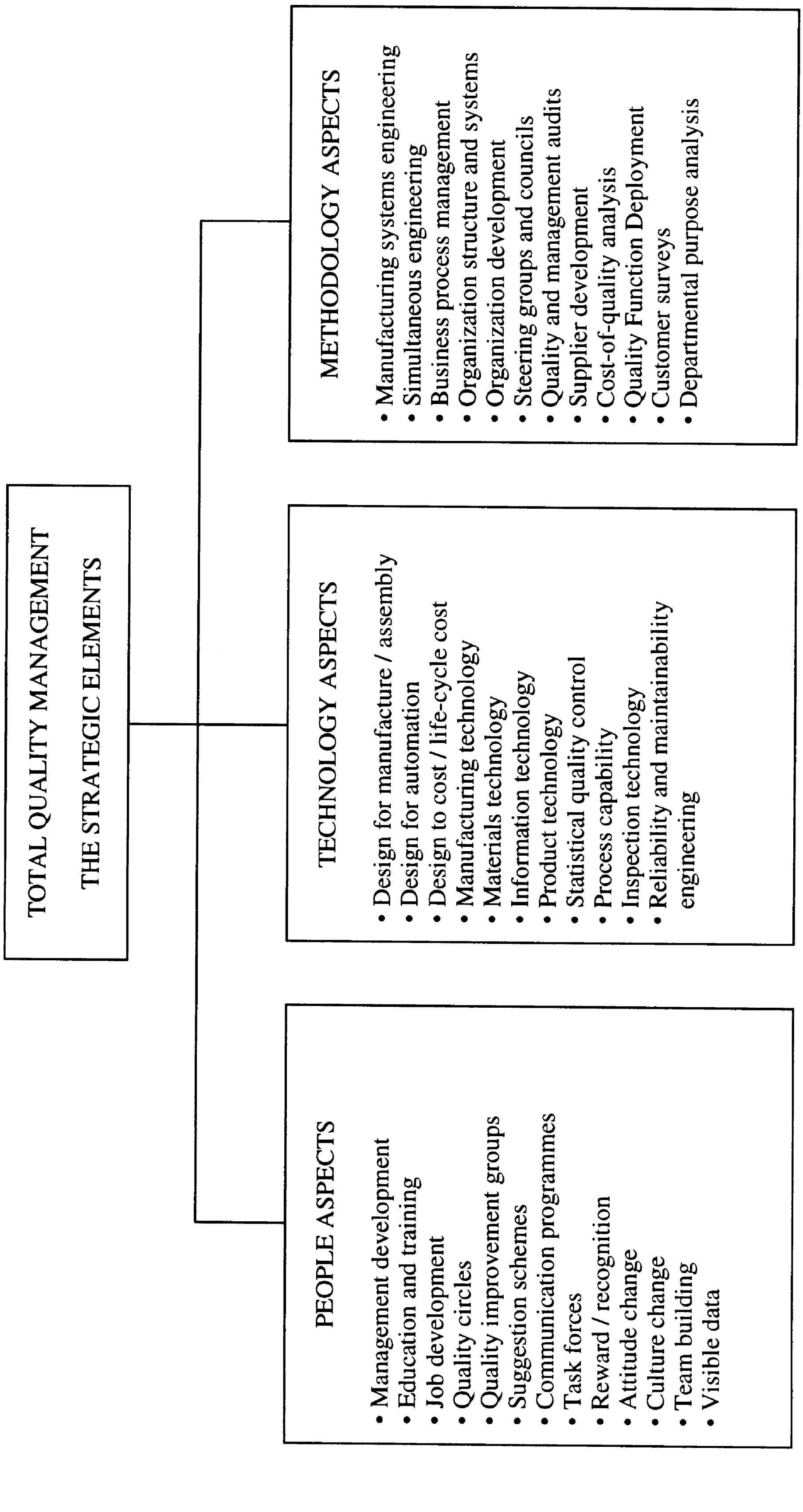

Figure 6.1. The elements of a total quality management strategy

technical service, in order to continuously increase the efficiency and competitiveness of the overall manufacturing activity.

Total quality management requires three main components:

- a complete management system;
- a statistical process control;
- teamwork.

With these foundations, it is possible to enact an implementation and development strategy, which allows continuous improvement.

The consequent strategy should be divided into three major aspects (as shown in Figure 6.1): technology, methodology, people (Oakland, 1989; Harvey, 1989; Hutchinson, 1990; Johnson, 1990; Wilborn, 1989; Mizuno, 1983; Hagan, 1983).

This strategy consists of five stages:

- recognition of the initial status;
- assessment of possible directions;
- definition of total quality development activities;
- application of such activities;
- increasing personnel skills.

Complex control activities are also included within this management.

Beyond being based on a series of actual controls at every level, total quality control is based on the diagnosis and analysis of the cause of errors and/or weak points of the entire manufacturing system.

Total quality and its control involve all vertical and horizontal areas within a company, both separately and interdependently among the various divisions (Mizuno, 1988; Feigenbaum, 1983; Vorley and Tickle, 1990; Lillrank and Kano, 1989).

A central point of total quality control is in design and development; if these two phases are well set and qualitatively controlled, the easier control is in the operative stages and the less likely errors are to occur (Bounds et al., 1994; Williams, 1994).

A total quality management and control inevitably leads to quality assurance and certification.

It should be specified that when a company decides to assure the quality of its products, in addition to controlling quality during the stages of the process and in the final product before use, it must make checks after prolonged use, since it would be damaging to assure a product — especially a durable good — which offers defects or problems after repeated use, or requires unexpected repairs or maintenance (Stebbing, 1989).

The organization of the control requires a considerable deployment of human, technical and financial resources, which must be compensated by increased income.

6.3. BEYOND TOTAL QUALITY MANAGEMENT

Quality has evolved from a discipline relegated to inspectors and technical experts to a strategic focus and a process-oriented approach to management that commands the attention of all employees, from the top to the bottom of the organization; but great modifications are still taking place, so that the traditional paradigm based on total quality management can be overcome by the emergence of a new paradigm, the so-called "Customer Value Strategy" (Bounds et. al., 1994).

The differences between the new and the old paradigms are organized around three themes: customer value strategy, cross-functional systems, and continuous improvement. In brief, the central idea of this paradigm is that *managers must think and act differently than in the past to improve organizational systems to provide superior customer value.*

Customer value is defined as the combination of benefits derived from using a product (or service) and the sacrifices required of the customer. The *customer value strategy* is the business plan for offering value to customers, including product characteristics, attributes, mode of delivery, support services, and so on. The theme of customer value strategy may be addressed in many topics, including quality, measurement, positioning, key stakeholder, and product design.

About quality, in the old paradigm managers consider quality in terms of meeting specifications; in the new paradigm, product quality is considered only one component of customer value, in a synergetic relationship with cost and organization. This direction means that improving quality by reducing variation in outputs reduces defects and costs and makes the global performance more reliable.

Also performance measurement has to be done in a broader way, by means of internally focused measures, finalized to analyze the impact on consumer value, in addition strategic decisions must be made by considering market segmentation and customer needs. In other words, customer are the key stakeholders.

Organizational systems are the means that provide customer value, and

they include all inputs, process technology, operating methods and work practices, information flows, and decision-making.

To implement the new paradigm, continuous improvement has to be made by scientific method to study changes and their effects, where error is considered an opportunity for learning and improving the whole system.

Moreover, all choices must be viewed in a long-term strategic perspective (e. g. to meet future needs, of course, without neglecting current needs).

Summing up, the key principles in a culture that supports the new paradigm include:

- the importance of determining what customers value as opposed to what management thinks they needs;
- a customer versus an organizational focus;
- a focus on optimizing organizational performance rather than maximizing functional end results;
- a focus on the processes and systems that result and not the results themselves;
- the importance of experimentation for knowledge and easy access to new information;
- mistakes that lead to organizational learning are acceptable;
- the importance of continuous improvement versus working to specification or adherence to the status quo;
- performance improvement comes from process/system improvement and not just improving people;
- to improve processes/systems, managers must seek out root causes of problems;
- continuous improvement is demanded at every level of the organization.

6.4. IMPROVING QUALITY AND PRODUCTIVITY

Once we have entered into the logic of total quality, it is easy to understand the relationship between quality and productivity; in the first place, the resources that must be jointly allocated, measures of performance, efficiency and effectiveness, the relationship between input and output, techniques, tools and methods used in the process, the process by which the resources are allocated for each task. The connections between quality and productivity have been illustrated by several Authors (Adam et. al., 1981; Schmenner and Cook, 1985; Edosomwan, 1988; Moir, 1988; Hradesky, 1988; Cullen

and Hollingum, 1987; Roth, 1992; Jones, 1991; Goetsh and Davis, 1994; Hart and Hart, 1990).

It may be emphasized that each marginal change in the amount of one or more inputs has effects on the total production and productivity levels, as each marginal change in the quality of one or more inputs affects the quality of the products and the productivity levels.

In order to understand when the productivity and quality levels are balanced, one may use a bell-shaped curve with a state of equilibrium at the centre, and low quality and productivity at the extremes.

Before defining and, therefore, applying the methods and instruments that allow improvements in quality and productivity, in-depth studies must be carried out, capable of identifying the weak points and causes of errors and defects in the manufacturing system.

The methods that may be used are:

a) frequency histograms: by representing the statistical dispersion of properties/performance in the units produced (thus the pattern of their uniformity/regularity), these provide the foundations for understanding changes in scene both in manufacturing and services, showing the opportunities offered by each area. The method, however, does not indicate all sources of change.

b) Pareto analysis: makes it possible to identify the vital problems and their entity. Thus it is a method for establishing the priority of actions to correct mistakes and concentrate on crucial points.

c) cause-and-effect diagrams: by correlating causes and effects in each area, these make it possible to identify weak points and how to eliminate them;

d) matrix analysis: makes it possible to identify the entity of errors in each division;

e) precision report: used to establish operating standards for new equipment;

f) control charts: these are statistical tools for measuring and showing the value of a characteristic of the product supplied by a process and its stages, and variations over time;

g) attribute control charts: these show the number of product defects based on established properties;

h) variable control charts: these show the degree of change in a single measurable quality attribute of the products.

Based on the data gathered during this learning stage, the value analysis is applied (Miles, 1967; Joineau, 1973; Tagliarini, 1989) either to establish

how a product may be improved without changing costs (quality improvement), or how a cycle may be rationalized and optimized without changing the product (increased productivity and efficiency and cost reduction).

Thus one arrives at a joint assessment matrix of productivity and quality, which indicates the possible combinations: from poor productivity and quality to the region of excellence (high productivity and high quality).

Of course, procedures must be implemented to minimize costs and maximize results (Fine, 1986).

The principles for ensuring success for quality and productivity improvement projects and strategies essentially consist of the following:

1) controls: objectives are defined, including the activities involved. In particular, parameters such as productivity ratios, cost curves, control charts, scheduling of the various activities, etc. are used. Gantt and Pert diagrams are very helpful;

2) co-ordination: may be achieved by closely linking the various sections, according to their specific competencies and responsibilities;

3) communication: the channels must be prepared to transmit the data gathered and results achieved in each section;

4) cost savings: procedures must be enacted aimed at using the lowest costs with respect to the results;

5) contribution analysis: this is a method that makes it possible to establish how much each stage and section contributes to the desired improvement;

6) co-operation: this is the crucial point, that allows various project components to work together, in order to achieve the desired and expected results.

6.5. THE ENVIRONMENTAL AUDIT WITHIN A TOTAL QUALITY STRATEGY

A company that tends to implement a total quality system cannot but be concerned about the environmental conformity of its products and procedures by creating an environmental management and care system structured according to the following points:

- a clear company environmental policy and the preparation of specific environmental programmes;
- the integration of environmental management into the organization and personnel training on environmental matters;

- internal structural controls on environmental impact, followed by the appropriate reports;
- periodic environmental audit.

Currently, various companies are involved in creating their own environmental management and care systems and carrying out environmental audits, although formal procedures have not yet been standardised and these are basically self-regulatory programmes.

The environmental audit, which represents a key instrument in the environmental management system of a company, may be defined as a systematic search by experts inside and/or outside the company to assess the potential environmental risks of routine work and the procedures followed by a company, and management of the related environmental matters, as well as to acquire all elements to optimize the use of resources. Technical and organizational aspects are examined in an integrated manner.

In most cases, the environmental audit is the first step towards creating an environmental management system (Ledgerwood, 1992).

The objectives of the environmental audit are:

- to verify the conformity of the facility, in all stages, to environmental standards;
- to verify and improve the internal environmental control;
- to create an information system to manage knowledge of the various organs that are part of the environment;

These objectives may be achieved by setting up an appropriate organization within each company, with qualified personnel to carry out these functions using suitable equipment.

The final aim is to make those continuous corrections at each stage of a process/system, in each equipment, to raise the safety and environmental quality level.

The advantages of an environmental audit may be summarized as follows:

- advantages in terms of cost savings: energy and raw materials savings, reduced waste and scrap, lower investments in technologies which remove pollutant wastes;
- advantages in terms of market: modern product policy, R&D advantages, competition, bigger market shares;
- additional effects: personnel motivation, greater consumer trust, public opinion, economic operators.

The Institut für Ökologische Wirtschaftsforschung (IÖW — Institute for

economic and ecological research) in Berlin has developed an integrated approach to the environmental audit, already used by various companies (Clausen, 1992).

Information regarding the materials used, the manufacturing processes, products and emissions allows the environmental effects to be assessed and is generally available to any company. The possibilities of developing alternatives to the existing products and processes are greater inside than outside a company.

The IÖW has therefore developed the environmental audit as an internal system for the environmental improvement of businesses involved. The basic element of such an approach is represented by the eco-balance, an instrument that takes into account the greatest possible number of environmental effects and concentrates its attention on the ecological problems of the life-cycle of all materials. The ecological balance of a company is derived from various specific balances:

- input-output balance;
- process balance;
- product life-cycle balance;
- plant-structural impact.

The company input–output balance gives an idea of all inputs and outputs of a company. The input is represented by raw and auxiliary materials, supplies and energy, while the output comes from major products and by-products, waste, waste water, dispersed heat, noise, etc.

The process balance analyses the input-output of a machine or manufacturing process and makes it more transparent. It will be possible to identify weak points, allowing considerable improvement.

The product balance gives an idea of the entire product life-cycle and ecological effects caused by manufacturing, the use and disposal or recycling of the product.

The product balance is important in the following instances:

- if it is believed that important ecological problems exist in the initial production or after-use period;
- to compare the product design to make strategic and ecologically valid decisions about products.

The fourth element of the eco-balance system is the analysis of the structural impact of the plant in question, listing the ecological effects of the plant such as landscape alterations, long-term soil contamination or the ecological risk of materials or products deposited on-site.

Obviously, such an organization has costs that may even be considerable; on the other hand, the economic benefit resulting either from increased safety or decreased amounts of pollutants released is certainly greater than the costs, as is the consequent benefit of the image of a "safe" or "clean" company, thus not damaging from an environmental standpoint (McIntosh and Campbell, 1992).

However, it should be pointed out that the activities and functions that must be created and organized for the environmental audit make up the modern concepts of business management, and thus fall both within the business risk and general costs. Thus the only relevant aspect in creating such control and correction activities is to set the "convenience threshold", which should be considered the maximum level of additional costs that may be sustained by the company in order to make the organization of the environmental audit effective in relation to the achievable benefits. These, however, are not always quantifiable because, as specified above, they often improve the image of the company or improve internal safety, but do not necessarily increase the value of the products. Only if the effects of the audit can be closely correlated either to company survival or its overall quality (translating into an increased value of the product sold) is it possible to determine the convenience threshold with precision.

In this case, it is helpful to calculate the "incremental income rate", by using the traditional ratios.

It may be stated that the threshold may also be very high, if the intrinsic features of the technologies and plants carry a high risk. This is the case, for example, of nuclear power plants and all chemical plants, for which systems for increasing safety already greatly add to both investment costs (up to as much as 50% for nuclear power plants), and in running and maintenance costs.

6.6. GLOBAL PERFORMANCE INDICES FOR QUALITY EVALUATION

Each product of technology exhibits a myriad number of property/performance factors that are linked to the specific use for which it is destined. Although the properties of the materials themselves are fairly easily listed and measured, durable goods such as automobiles, industrial vehicles, motorcycles, airplanes, household appliances, office equipment, processors, farm machinery, etc. perform in ways which are often complex and difficult to express in quantitative terms.

Moreover, the more complex the product (composed as it is of myriad components), the greater the complexity of the performance which is evaluated, both at the production stage and later, during use.

In such cases, particularly when technical and economic comparisons need to be made, it can be very useful to have at one's disposal an index which synthesizes all the principal property/performance elements involved. In addition, a global performance index (GPI) allows for a comparative evaluation of a product to be carried out over time, given that, owing to technological dynamics, certain properties may improve and others undergo some form of deterioration. In order to devise such an index, three steps must be followed:

- definition of the properties which influence a global qualitative assessment of the product's merits
- determination of the methods for quantitatively measuring these property/performance factors
- fixing the procedure for obtaining a synthetic index (or GPI).

A critical as well as analytical evaluation of every possible property/performance factor contributing to this global index will inevitably lead one to exclude some of the properties mentioned in the first step, because they are difficult to quantify. Obviously, each product category must be considered according to its own particular qualities. For example, with automobiles the property/performance factors most relevant to any judgement of global qualitative merit such as that inferred from a GPI are: acceleration, fuel consumption, braking distance, probability of any defects occurring in ten vital components within 50,000 km, substitution time of five vital components, crash test (speed of impact against a wall with no harm to the occupants), amount of carbon monoxide and nitrogen oxides emission and, finally, noise levels.

Similar properties pertain to be categories of diverse motor and industrial vehicles. The number of property/performance factors contributing to a complete, global appraisal is even higher for civil and military aircraft — a fact which reflects the greater overall complexity of these products. They include: take-off and landing distances, minimum turning radius and maximum angle of climb, speed of stall, maximum speed, aspect ratio, maximum aerodynamic coefficient, and also the peak load factor, operating range, fuel consumption relative to maximum speed, engine power relative to total weight, the probability of defects occurring in eight vital components within 1,000 hours

of flying time, the substitution time of three vital components, tensile strength of the rotating engine parts, and the resistance to fatigue of the wing material.

As far as motorized farm machinery is concerned, relevant performance factors include: work capacity-engine power correlation, hourly fuel consumption, substitution time for three vital parts, and the probability of defects occurring in these within 5,000 working hours.

The evaluation of car air conditioners is based on factors such as: cooling power, thermal dispersion in the passenger compartment, electrical and mechanical power absorption, speed and temperature of entering air and, finally, the air temperature and humidity levels in the passenger compartment.

For products such as food containers, the correlation between deformation resistance and weight of the materials, along with their capacity for resisting alteration upon contact with foods is important.

Clearly, various other property/performance factors may take on importance, perhaps even more than had at first been hypothesized, and it must be stressed that, while at times the highest values are the most favourable, at other times the lowest may be, depending upon the factor under consideration.

Methods allowing for the expression of such property/performance factors must have the merit of being easily duplicated, as well as being standardized on a world-wide scale. Only in this case will a global qualitative assessment have general validity and be able to be employed not only in technical-qualitative evaluation but in those of an economic and commercial nature as well.

Procedures regarding numerous property/performance factors have already been highly standardized, tested and approved. Others require a still higher level of specification and definition, particularly those which are atypical but which grow ever more important for product definition and qualification.

The method for the elaboration of GPIs proposed is the one utilizing nomograms, which has been successfully adopted in dealing with several products, such as automobiles, aircraft (Barbiroli, 1989b), polymeric materials (Barbiroli and Fiorini, 1992).

Firstly, the intermediate quality indices must be elaborated and the property performance factors matched up in logical order. The main difficulty in this step is ranking the properties according to a scale of values.

If any two properties are deemed of equal value, then the scale of the synthetic index will be situated in the very centre of the nomogram. If, on the

other hand, two properties are seen as having differing weight, then the scale will be moved towards either one or the other property, according to its relative importance.

If we consider the properties, as listed above, of goods such as automobiles, airplanes, other motor and industrial vehicles, farm machinery, car air conditioners, and food containers, then it would seem most logical to assign equal value to each. Naturally, such a choice is open to criticism, as is the option for employing differentiated weights. Yet, whereas equating the relative importance of each property has no effect upon the final result, different weights does.

It is clear that every property or hierarchy of properties would be treated subjectively (i.e., differently) by each consumer. It is precisely because of this that we have opted to equate them, thus avoiding any need to establish hierarchies, none of which could possibly meet with unanimous approval.

In Tables 6.1 and 6.2 the values used in the elaborations for automobiles and aircraft are reported as examples. The parameters proposed for each category permit us to identify significant GPIs that also show up the often substantial differences between analogous products.

The value of the proposed procedure is mainly methodological. The method is not immune to variations, both in its utilizable parameters and in their combination and parameterization. Before arriving at any definitive proposal for the various products, i.e. at one in which the values of the final GPIs would be uniform, a careful evaluation by experts in each field of all the aspects contributing to the global performance of each single product is necessary. Furthermore, should the nomograms, despite their validity, come to be considered an excessive simplification, suitable algorithms can be adopted instead, once the parameters and their relative units of measure have been defined. The procedure is the one proposed in Section 1.5, and has given positive results in the numerous cases where it has been applied.

6.7. THE RELATIONSHIP BETWEEN PRODUCT QUALITY AND VALUE

The term "value" has several meanings, which express different concepts. It can be meant both in an objective and subjective sense: the former can refer to the theory of labour-value, the latter to the variable value of a specific good in relation to different conditions (place, time, utilization, market, etc.).

TABLE 6.1. Utilized parameters for automobiles

Property/ performances	Sub-indices		Unit	Variation range	Standard measuring conditions	Examples (A)	(B)	(C)	(D)
Time for substitution of five components	Maintenance		hours	4 – 20	Front and posterior linings, front and posterior shock absorbers, clutch, distribution, silencer terminal	9	8.30	13	10.30
Probability of defects in ten components within 50,000 Km	Maintenance	Management	%	0 – 100	Brakes, clutch, gearbox, electrical system, drive, suspension, pistons, distribution, body, air-conditioning	25	20	30	30
Acceleration from 0 to 100 Km/h	Efficiency	Management	seconds	5 – 50	With four passengers	16.2	23	12	16
Fuel consumption	Efficiency		MJ for 100 km	100 – 1,000	At 120 Km/h with four passengers	450	400	370	350

TABLE 6.1. Utilized parameters for automobiles (*continued*)

Property/ performances	Sub-indices		Unit	Variation range	Standard measuring conditions	Examples (A)	(B)	(C)	(D)
Crash test	Safety	Functionality	km h^{-1}	50 – 100	Impact speed against a wall without damage to passengers	60	55	60	55
Braking distance at 120 km/h	Safety	Functionality	m	40 – 90	With four passengers	60	65	65	65
Amount of carbon and nitrogen oxides	Pollution	Functionality	ppm	5 – 30	Detected at 2/3 of max power	0.3+10	0.4+11	0.5+12	0.4+13
Noise levels	Pollution		dB_A	50 – 100	At 120 Km/h, with closed windows	70	76	75	73
GLOBAL PERFORMANCE INDEX						62.3	57.7	57.2	57.3

TABLE 6.2. Utilized parameters for aircraft

Property/ performances	Sub-indices			Unit	Variation range	Standard measuring conditions	Examples A	Examples B
Take off distance	Agility	Maneuvrability		m	200 – 2,000	Full weight	1400	1600
Landing distance				m	200 – 2,000	Full weight	800	900
Tightest turn minimum radius	Mobility			m	200 – 2,000	Full weight	870	980
Steepest climb angle			Safety	deg	10 – 20	Full weight	1.2	1.7
Aspect ratio (AR)	Aerodynamic	Dynamic stability			1 – 21	Ratio of the wing span to the average chord	6.2	7.0
Max aerodynamic coefficient					3 – 33		8.2	9.2
Stall speed	Equilibrium			km h^{-1}	100 – 350	Full weight with full flaps and gear down	260	280
Max speed				km h^{-1}	200 – 2,000	Full weight	11.80	11.00

TABLE 6.2. Utilized parameters for aircraft (*continued*)

Property/ performances	Sub-indices			Unit	Variation range	Standard measuring conditions	Examples A	Examples B
Max load factor	Range	Efficiency	Management	g	2 – 10	Full weight	5.3	5.5
Max endurance	Range	Efficiency	Management	hours	4 – 14	At max speed and full weight	10	11
Max fuel flow Max speed	Yield	Efficiency	Management	lb h^{-1} km h^{-1}	0.1 – 2.0	At max speed and full weight	1.00	0.78
Max engine power Max gross weight	Yield	Efficiency	Management	lb lb	0.2 – 0.4		0.34	0.38
Probability of defects in eight components within 1000 flight hours	Maintenance		Management	%	0 – 10	Turbines, tanks, electric system, directional system, doors, gear control equipment, fuselage	2	2
Time for the substitution of 3 vital components	Maintenance	Functionality		hours	50 – 100	Turbines, flaps, gear	70	90
Fracture resistance of engine moving parts	Reliability	Functionality		N mm^{-2}	50 – 100	After 2,000 hours of uninterrupted engine working	85	90
Fatigue resistance of wing materials	Reliability	Functionality		Number of cycles per failure	10^3 – 10^5	After 2,000 hours of uninterrupted working	50,000	60,000
GLOBAL PERFORMANCE INDEX							60.0	57.0

Economists have hardly ever considered the quality of commodities in a close relationship to their value.

Since, on the contrary, quality is the fundamental reference point to state the degree of usability of a commodity, there should be a straight correlation between quality and economic value. This correlation, however, does not exist for the majority of commodities, but there are great discrepancies and unbalances, as a consequence of specific market structures.

In order to define the value of commodities, two ways can be followed:

a) to calculate the real production cost by considering its "production value", calculated through industrial accounting, which takes into consideration all costs involved in a process (raw materials, energy, investment, labour, management, non-material inputs, etc.);

b) to consider the "objective value" of commodities, referred to their global quality (properties/performance), which makes it possible to characterize their technical and economic utilization.

The first method takes into account the real conditions a good is produced (technical coefficients, technology and unit cost of each input); in the second method emphasizes the function of properties/performance in relation to its utilization.

The difficulty consists in establishing "the minimum reference price", which leads to the calculation of its "use value".

If we analyze this point, we can state that the concept of "specific value" of a product or a service gets considerable importance in case of a free entree market, because competition stimulates the quest for alternative solutions and determines the search for increasing quality and higher value in relation to the price.

Therefore, it is particulary useful to set up valuation parameters able to measure the level of quality and, at the same time, the economic value of a product related to its performance.

The "relative value", obtainable by the ratios price/performance and cost/performance, can be more meaningful for carrying out analyses and comparisons than the "absolute values" (prices and costs).

To this purpose, global performance indices can be elaborated by selecting and combining the most significant properties/performances, according to the method proposed and reported in Section 6.6.

The ratios cost/global performance and price/global performance make it possible to prepare order of merit, based on the "relative objective value",

and, consequently, to identify and assess the entity of discrepancies, within several equivalent solutions.

These ratios, therefore, are useful both for consumers and producers who are interested in increasing their knowledge about technical and economic aspects of production activities, so as to establish which are the products more suited to satisfying their own needs and purposes.

For basic materials — such as steel, light alloys, polymers, chemicals — there is a fairly good coherence between cost (or price)/global performance; for the majority of durable goods there is a low coherence, for all non-essential goods there is no compliance at all (gems, furs, etc.).

The main problem in elaborating global performance indices is the insertion of subjective properties, which are not measurable; thereby, quantitative evaluations can be carried out only by emphasizing the importance of the quantifiable properties, both at the production and the consumption stage.

Chapter 7

ECONOMIC EFFECTS OF TECHNOLOGICAL DYNAMICS

7.1. THE MULTI-DIMENSIONALITY OF EFFECTS

Technology, however it is used, produces a number of economic effects. Each of these effects nearly always has both positive and negative aspects, which must be properly weighed up in order to make choices coherent with the objectives of a progress policy.

The many effects produced by technological dynamics can be identified at various levels, from individual companies to the overall economic system.

We should immediately point out that the basis common to all effects, whether positive or negative, should be sought in the characteristics of each technology and in changing productivity levels.

Indeed, a new technology that partially or totally changes a manufacturing process inevitably acts upon the relationships between the production factors used; since new technologies are introduced in order to achieve better economic results than were possible with the previous technologies, the main objective to be achieved is increased productivity. Obviously, higher productivities mean reduced average unit production costs. In addition, lower unit production costs probably mean greater competitiveness in the market and an increased market share for the company.

Of course, technological innovation in and of itself may often not be enough to achieve these objectives, but must be accompanied by a more general growth of all typical functions of the company: so, for example, if an increased production potential due to technological innovation does not coincide with an increased organization of the company management, and more intensified marketing and technical service, the benefit from the technological innovation on the inductive process will not be translated into a real benefit for the company.

Proceeding along this schematic analysis of effects, it should be further emphasized that it has often occurred, in all the industrialized countries, that, while the introduction and diffusion of new technologies has led to an undeniable economic advantage for the companies that adopt them, has on

the other hand created other problems in the overall economic and even ecological system. In this regard, it has been stated that the main problem to be solved in future years will be that of making technological and manufacturing choices that are advantageous — though to different degrees — both to companies and to the entire economic system.

It is therefore necessary to systematically and analytically examine the overall effects that the various manifestations of technological dynamics cause at various levels: on natural resources and raw materials; on industrial productions; on the economic systems; on the economic significance of commodities and purchasing power; on the ecological systems.

7.2. EFFECTS ON NATURAL RESOURCES AND RAW MATERIALS

In order to deal with this first aspect analytically, it may be useful to distinguish, however approximately, non-renewable from renewable resources. The former cannot be reproduced by nature, although they may be recovered and recycled; the latter, on the contrary, may be periodically re-obtained. Non-renewable resources are those obtainable from the lithosphere (fuels, minerals) and atmosphere (oxygen, nitrogen, helium, etc.); the latter, those obtainable from the biosphere (agricultural-industrial and agricultural-food products) and from the hydrosphere. The distinction is largely upheld by a number of situations, including the commercial features of resources, the manufacturing means necessary in order to obtain them, manufacturing organization, current and future availability.

A) Non-renewable resources

Technological dynamics produce different effects on:
- extraction and processing techniques for raw materials;
- how raw materials are used;
- finding new deposits and new areas;
- costs and prices.

These effects act at different times and by different means, and thus we shall deal with them individually.

Effects on extraction and processing techniques for raw materials. By improving extraction techniques, technological dynamics can considerably ex-

pand and change the geographical distribution of reserves, both by exploiting mineral deposits with low metal content, and by creating techniques for exploiting unconventional mineral deposits.

Concerning the exploitation of mineral deposits with a low metal content, technological dynamics can offer radical improvements in extraction and processing techniques, expanding the availability of economically utilizable resources, even if there are significant obstacles.

If we examine the average concentration of elements in the earth's crust and compare it to the concentration currently utilizable from an economic standpoint, we notice a deep discrepancy between utilizable deposits (reserves) and unusable deposits (resources).

Technology can thus make economically accessible vast deposits that are currently not exploited, since it can expand the concept of reserve.

It is the latter group that is affected by technological dynamics, which over time converts many unusable deposits into reserves.

Let us consider a few significant situations.

Currently, aluminium is extracted from bauxite having a content of close to 50% of alumina, through an electrolysis process that requires high electrical energy consumption. However, at the same time processes are coming into use that offer higher yields, and completely new technologies are now in the pilot stage making it possible to eliminate or reduce the two current negative parameters that affect aluminium metallurgy: energy consumption and use of bauxite.

A similar situation occurs in titanium production. This metal can be extracted from two minerals: rutile and ilmenite.

Over the years, studies have been made to prepare ilmenite handling processes competitive with current metallurgical processes using rutile. Should these processes be adopted, the geographical framework of distribution and production of titanium minerals would be profoundly changed. Nickel is produced from sulphides (Canada) and silicates (New Caledonia), minerals rich in metal and whose metallurgy is well known and economical. We must also bear in mind that approximately 70% of the world's reserves are represented by lateritic minerals of nickel and iron, currently little used due to the difficulty of extraction and metallurgical handling. However, this does not preclude the possibility in the future of the technology for extracting nickel from lateritic minerals becoming sufficiently economical and competitive. The use of a new type of mineral in countries other than those where production currently takes place may also represent one of the rea-

sons that can alter the structure of the world nickel market (Barbiroli and Ballini, 1973).

Effects on how raw materials are used. How raw materials are used is another factor which, in the medium and long term, can cause profound changes within the socio-economic context of a country.

For decades petroleum has been considered the typical energy source, and the problem of an alternative use for it has never been posed. As a consequence, even estimates concerning the possible duration of petroleum resources have always been made through extrapolations that consider the usage rate of petroleum deposits to be a constant. On the other hand, it is beyond doubt that a different policy for using petroleum, geared towards using it as a fundamental raw material in organic synthesis industries, would shift in time the period for depleting petroleum resources.

One should also keep in mind that there are many needs that push towards the use of coals by processes of conversion into liquid hydrocarbons, which are close to technological maturity and affordability.

Recycling also lends itself to certain considerations regarding a different way of dealing with the problem of exploiting resources. Recycling makes it possible to achieve considerable energy savings on the one hand and, more importantly, to change the commercial balance of poor countries for the better. All of this demonstrates the growing tendency in many countries to mature manufacturing orientations, so as to change the criteria upon which raw material purchases are based.

Other examples show how a different use of raw materials can profoundly change the commercial relations between countries, and distance fears of rapidly depleting resources.

The most obvious case is the use of copper and aluminium in transporting and distributing electrical energy. It should be emphasized that the available quantities of copper and aluminium are quite different; in addition, copper minerals are affected by the law of decreasing yield, thus as the metal content of the mineral decreases, the amount of energy required for extracting, grinding, and floating is in excess proportion, with a pattern very close to a hyperbola (Chapman, 1974; Roberts, 1974). On the other hand, while aluminium does not escape this law completely it is much less affected, since the amount of energy necessary for treating bauxite is almost entirely unrelated to the percentage of metal present, since most of the energy is required in the final stages of the metallurgical process, that is the electrolysis of alumina. The production of aluminium also lends itself to considerable technological improvements.

Here again, the use of aluminium in place of copper would profoundly alter the structure of the world's copper market, too often subject to sharp oscillations in quotations due to political reasons and speculation, and use would be made of a raw material such as aluminium which is widely available and whose quotations on international markets are more stable (Ballini and Barbiroli, 1976).

Effects on finding new deposits and areas. Over the short and medium term, technology can aim at exploiting conventional mineral deposits by discovering new deposits, or improve extraction techniques to allow exploitation of minerals with an ever-lower metal content.

However, there is no doubt that over the very long term there is a high potential in systematically exploring entire regions of the globe, as yet almost entirely unknown as far as the existence of mineral deposits is concerned.

We know very little about the entity of mineral deposits on the ocean floor, which due to their importance are the next step to be faced by extraction technology in the medium and long term.

The Antarctic, due to its climate and international law, is still largely unknown, although it is certain that it does possess extensive mineral deposits (Rose, 1976).

There is the problem of preparing extraction techniques to exploit deposits much deeper than those currently used.

One of the factors that will certainly change the geographical framework of mineral resources in coming decades is the exploitation of sea floor mineral deposits.

This will not only lead to a further expansion of available resources, but will considerably change the international trade relations that currently link raw material exporting countries and consumer countries. There are obvious reasons that arouse growing interest by industrialized countries in undersea mineral extraction, especially the increasing demand of minerals and the deplation of traditional deposits.

As far as aspects regarding the economy of undersea mineral extraction is concerned, it must be pointed out that as of today, the cost sustained for the entire operation of exploration, mineral extraction (polymetallic nodules), conversion, etc. is still greater than the price currently obtained on the markets. However, it should be emphasized that the economy of the process may be evaluated objectively only when pilot systems become mass-production plants, to take advantage of the economies of scale available to the latter.

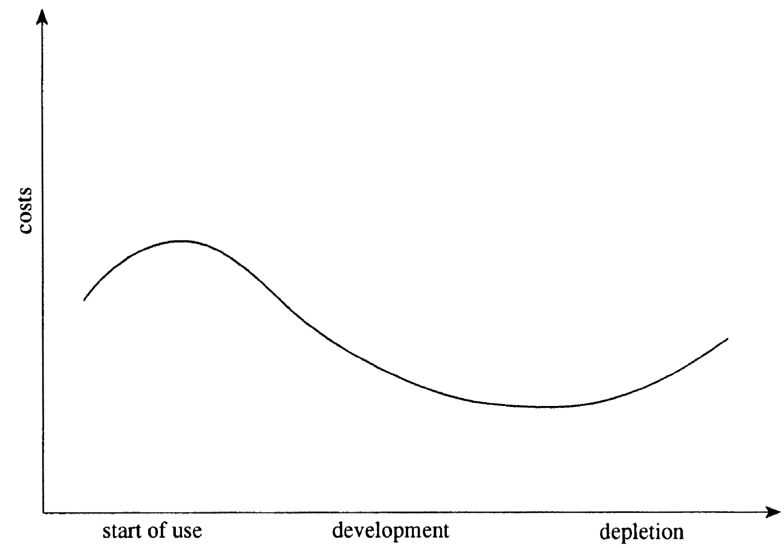

Figure 7.1. Cost pattern for non-renewable resources during the various stages of its usage cycle

Regarding prospecting and exploiting very deep petroleum deposits, whether on land or the sea bottom, here again technological dynamics can provide positive results. The current geographical distribution of petroleum reserves is nothing other than a photograph of a real but static situation, in which technological dynamics has a purely relative role. However, it is certain that deposits with a vast potential are present in numerous regions of the globe, but not always located in typical production areas.

For deep-sea petroleum extraction, for some years prospecting has been carried out from platforms located in areas a few hundred metres deep.

Effects on costs and prices. The intense changes in technologies lead to highly significant economic results, though differentiated according to the stage a technology is in. In the development stage, productivity increases in greater proportion than costs, and thus the average unit costs decrease. In the maturity stage, growth in productivity is in proportion to total costs, and thus average unit prices are stable; in the impoverishment stage, productivity increases less than in proportion to total costs, and therefore average unit costs rise.

The pattern of the economic cycle of a raw material — which reflects that of the technology used to process it — is shown in Figure 7.1.

We should point out that it is nearly impossible to recreate this cost pattern, for two reasons: the production costs of a raw material are never

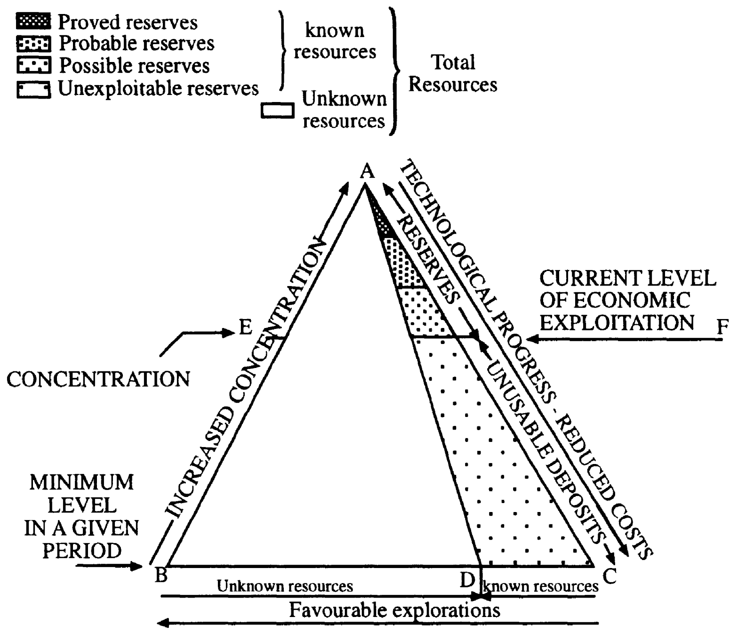

Figure 7.2. Total amount of a resource and changes in reserves according to the technological and economic level

known, and most of all, they are not known for a very long period of time, the life cycle of a raw material (which may last several decades, if not centuries).

As far as prices are concerned, they are formed according to complex rules which are, often prevailingly, affected by "exogenous" factors with respect to the production stage; the main consequences are that prices differ widely from the costs and fluctuate greatly.

It often occurs that, even when costs decline in the development stages of a technology, prices rise; the opposite is also true.

In other words, prices are not correlated to costs and production. Thus one is never able to assess the real technical-economic situation of a resource in a given moment through prices, nor its quality.

When a raw material and its relative technology have exhausted their stage of development, and thus their positive economic stage, technology may intervene once again as a "replacement technology", to allow one resource to be replaced by another; the degree of replacement depends on the characteristics of the products in which the material is used and the relative composition of the final product. These elements make it possible to define the maximum possible value of the replacement fraction. As costs increase, the potentially replaceable fraction increases.

Given the dynamic nature of estimated reserves and resources, as a summary it is useful to trace a conceptual model of the relationship that joins them (Govett and Govett, 1974).

In Figure 7.2, area ABC represents the total amount of resources of a given mineral.

The absolute amount of a particular metal consists of the lowest limit of concentration which it is economically possible to achieve within a certain time interval (line AB).

The proportion of known resources is represented in the graph by area ADC; additional discoveries of new deposits (line CB) will expand the portion of this area.

The separation between unusable deposits and reserves is indicated by the line EF, which is a function of technological progress and economic factors.

An increase in the demand, or improvements in extraction techniques, or an increase in prices will lower the line EF, transferring part of the unusable deposits to the reserve category.

At the same time, a constant production/reserves ratio tends to stabilise the line EF, which may also move upwards: a reduction in the prices of a metal forces deposits considered to be actual reserves to become unusable deposits.

As far as reserves are concerned, these may be classified from a technical and economic standpoint in three categories, characterized by an increasing degree of uncertainty:

- certain deposits;
- probable deposits;
- possible deposits.

B) Renewable resources

Technological dynamics has a series of effects, though of varying intensity, on renewable resources:

- on global productions;
- on productivity and the quantity of products;
- on costs and prices.

Effects on global productions. As far as findings of new areas are concerned, technological dynamics makes it possible to extend cultivable areas, though this may be done at the price of surpassing considerable limitations.

The possibility of further extending the area of agricultural crops is extremely limited in Asia, Europe, and part of the former Soviet Union. In Northern Africa and the Middle East, agricultural development is linked to the possibility of creating a vast and efficient irrigation network; tropical Africa and the Amazon basin have large regions that may potentially be used for crops, but the difficulty of cultivating lands — usually not especially fertile — in which the organic substances in the soil rapidly decompose in the tropical climate must be emphasized, as it requires continuous, high doses of chemical fertilizers.

In reference to climatic features, approximately 36% of the earth's land area is defined as arid, for a total of 48,858,000 sq. km.; of these, 40% has a semi-arid climate, with an average annual precipitation rate between 250 and 500 mm; another 40% is arid, with rains varying from 100 and 250 mm/year; the remaining 20%, with a rain rate of less than 100 mm/year, is considered extremely arid.

In the semi-arid zone, when precipitation is close to 450–500 mm/year, fair agricultural production is possible to achieve, especially for wheat, sorghum and millet; below this rain level, the yields diminish rapidly if no irrigation is carried out.

With respect to the 1,450 million hectares dedicated to permanent crops, only 223 consist of river-irrigated agricultural land; the rest of the land covers its water needs only through atmospheric precipitation. Overall, the surface area linked to irrigation is quite modest with respect to the total cultivated area.

The basic problem thus is not that of finding new lands, but rather covering the water needs of the lands, which is the real limitation to cultivating additional terrain.

From this explanation, it is clear how the problem of extending the cultivable surface area involves solving highly complex problems. Estimates of how much land can be cultivated vary widely, but their utility in practice is purely relative since until now it has not yet been specified at what cost this land can be made productive, or at what price level the crops would become remunerative.

It can be seen, therefore, that at the level of renewable resources the distinction between the concepts of resources and reserves returns, though in a less distinct form and the dividing line between the two lies in the economic limitation.

In order to become meaningful, estimates on new cultivable land must in-

clude capital, technology, and energy inputs together with the estimated cost of the product obtained from the cultivation in a new area.

About fish farming, after a remarkable increase in the last three decades, the environmental constraints have become limiting factors to further increases.

Effects on productivity and quality. Greater efforts by technology have been addressed not towards cultivating new areas, but rather towards achieving increased productivity, made possible by massive use of fertilizers, pesticides, improved crop varieties, use of irrigation and mechanization; however, the current world food production has very poor prospects of increasing because of the scarcity of arable land on the one hand, and the negative impacts of atmospheric factors on the other. Environmental impacts of traditional methods of cultivation using fertilizers, pesticides and herbicides have also complicated the problem enormously. For example, during the last 40 years about 400 million hectares of arable land have been lost through erosion or abandoned because of environmental degradation. Moreover, the quantity of groundwater available for agriculture and civil usage is declining each year, together with some important food sources such as fisheries. Clearly therefore, urgent attention needs to be given to this problem, especially to new and emerging technologies for food production and nutrition.

New agricultural biotechnologies (ABTs), in place of the Green Revolution Technologies (GRTs), seem to offer — at least in the long-term — new tools and an institutional framework to address problems of agriculture and hunger in both prime and marginal lands, in both developed and developing world. The developing countries, bilateral and international donors, and numerous non-governmental and private-sector participants must now consider a variety of environmental, economic, cultural and nutritional issues when choosing these technologies (Mannion, 1992; Goodman et al., 1987).

Emerging agricultural biotechnologies (ABTs) offer the promise of reducing hunger by: (i) increasing food production; (ii) lowering costs of food production and consumption; and (iii) developing food products to meet the special needs of the nutritionally deprived groups. Both proponents and opponents forecast that the ABTs might change plants, agronomic methods, production procedures, and, ultimately, rural, industrial and indeed world dietary habits.

The great challenge for agriculture in the future will be how to increase food production substantially, while at the same time reducing the input of chemicals. Biotechnology may offer ways and means of meeting this challenge. Specially selected or genetically-modified bacteria can play a role in improving soil fertility (Stickema, 1991; Buckwell and Moxey, 1990). Modern biotechnology also offers the possibility of introducing genetic information which encodes resistance to certain pests. In this context the transfer of genes across species barriers is very useful because, during evolution, many strategies for controlling competition between living organisms have already been developed. However, considerable worries are arising about moral and health consequences, and these are a strong limitation.

In addition to plant-improving technologies, ABTs offer improvements to cropping system through genetically-engineered organic management of crop residues. Enhanced symbiosis between soil microbes and plants, and multiple-cropping agro-forestry, offers the promise to restore and maintain soil and to provide diverse sources of food and income. Such possibilities are considered to be particularly relevant to Africa and to those regions of Asia and Latin America where GRTs have either not been implemented or have had minimal impact (Lambert and Joos, 1989).

Also animal biotechnology shows great potential for rich and poor countries alike.

Technological evolution has also made it possible to improve the quality of major crops. In particular, as far as the protein content of various vegetable products is concerned, there has been a considerable change in the amino-acid content, improving the balance among amino-acids: this is the case with some types of corn, for which varieties have been prepared distinguished by an increase in the proteic fraction of percentages of lysine and tryptophan.

New varieties of wheat with a high protein content have been developed, increasing the content from 14% to 18% without reducing productivity; similarly, lysine percentage increases of up to 30% have been recorded for barley. Another significant example is rice. The relatively high lysine content gives rice proteins the highest biological value among all grains; on the other hand, the overall protein content remains rather low, and in some cases negative correlations have been found between protein content and yield.

Qualitative improvements have been made in the zootechnics sector as well, combined with an increase in the number of heads, aimed at achieving

generations of animals with an ever-increasing productive capabilities. This is the result of a more in-depth knowledge of genetics and the development of environmental conditions suited to allowing maximum yield.

Effects on costs and prices. Technology has various implications on the prices of renewable raw materials, though in order to achieve them they require many non-renewable resources (fertilizers, pesticides, energy sources, machinery and thus materials, etc.).

Since overall productions increase slowly and in an unstable fashion, and since renewable resources suffer heavily from the effects of atmospheric agents, the cost trend tends to be more difficult to track than is the case for non-renewable resources.

However, they do tend to increase — though irregularly and unpredictably, given the special conditions in which products are obtained. On the contrary, prices are more stable over time, and follow more controllable criteria.

This is more marked for agricultural-industrial products, such as vegetable and animal fibres, wood, natural rubber. Among agricultural-food products, only soya beans tend to be stable.

7.3. EFFECTS ON INDUSTRIAL PRODUCTIONS

We must distinguish between two periods, with different features: before 1974 (first oil crisis) and thereafter.

During the first period, which began during the industrial revolution, the intensive nature of innovative processes and technological change led to profound changes in the production structure. Technological progress applied to manufacturing systems, whose objectives were mainly aimed at increasing productivity and reducing costs, led in consequence to an increasingly high specialization of machinery and a growing increase in the size of production units.

The evolution of specialization has made it possible to have productions characterized by economies of scale and continuous flow, high in quantity, with homogeneous products and, in any case, suitable for reducing the capital/product ratio. Such productions are commonly known as "mass". Processes of innovation and change have thus shown their positive effects by reducing the share of labour costs and costs of raw materials per product,

as an effect of stabilized quality and decreased unused quantities, eliminating costs due to stoppages, down-time and other discontinuities in manufacturing. On the other hand, the costs of research, plants, maintenance, etc. have increased. However, such increases — directly related to technological progress — are more than compensated for by the above-mentioned cost reductions thanks to the considerable increases in quantities produced.

The result thus becomes lower costs per product unit.

Specialization, however, has also inevitably generated negative effects: among these, in particular the increasing rigidity of plant conversion. It is indeed "normal" for "highly automated and extremely high-yield plants to be fairly inflexible, meaning that they cannot be converted to similar productions without high additional costs". Thus the risk connected to forecasting errors as to the obsolescence of machinery and technological self-financing has also increased.

In short, given the escalating speed of technology life-cycles and growing plant costs necessary to take advantage of them, forecasting errors regarding economic life have led to incorrect depreciation plans, to the point of preventing financing of new manufacturing technologies, or even to the point of failing to recover previous investments, with consequences that are often irreparable in terms of expansion if not survival.

We must now mention another phenomenon that particularly highlights the economic significance assumed by large companies in general. We are referring to the internationalization process of the largest industrial complexes. This process is the consequence of three distinct phenomena:

a) the need to place productions outside the domestic market because, due to the technological intensity and the quantitative limitation it places on the goods produced, this market is no longer sufficient in order to absorb supplies;

b) the need to recover the considerable expenses sustained in R&D, for designing new manufacturing processes and new products, etc., by increasing new sales;

c) the need to gather increased finances, which leads to unifying companies in different countries or gathering local capital in countries where it is convenient to expand production.

In each case, multinational complexes represent the latest evolutionary business form that has appeared in capitalist systems. This evolution, caused by the intense rate of innovation and change based on the limitations of increasing specialization and the incremented minimum plant di-

mensions, has taken several intermediate or final goods to become mass productions.

The very structure of international trade tends to alter as technology changes. Each country has characterized its exports by supplying goods whose production has made intensive use of the factor relatively most abundant and least expensive available in that country.

If we observe the export structure in various countries, it is obvious that those who are technologically stronger and have a higher innovative content export goods with a high technological content, and continue to expand their market share. This is the case for countries such as Germany, France, Japan, United States.

In other words, a country where labour is cheap and capital is expensive should export highly labour-intensive goods and import highly capital-intensive goods.

Each product and each manufacturer has a dominant cycle and international position that may be lost. This occurs because as the product evolves, the manufacturing processes become more rationalized and integrated and the product quality more standardized; production costs reflect less and less the availability of entrepreneur and skilled labour, and more and more the availability of unskilled labour and low-cost raw materials.

In these conditions, the advantage held by technically sophisticated countries disappears, and production shifts towards those less-developed countries who possess an adequate infrastructure and potential to adopt and imitate technologies developed elsewhere.

However, it has been stated that international market shares are strictly correlated to the innovative capacity of industry (Vernon, 1970).

Falling market costs of goods do not fall for an unlimited period of time, but instead end at the moment when additional, growing costs of investments in new equipment do increase productivity, but not in proportion to the increase in overall costs; therefore, costs increasingly affect each unit of goods.

The current, new stage of the technological revolution — begun after 1974 — is causing a substantial change in the connotation of goods: the so-called "dematerialization of goods", encouraged by information technologies, is a result of the scarcity and high cost of the production factors "energy and materials".

Dematerialization also appears as a tendency to change from "product" industry to "function" industry, based on which new services incorporate

functions previously carried out by highly material- and energy-intensive products, and services with a high scientific-technological content are being defined, based on the function. As an example, it is worth recalling the conversion of the fertilizer industry to the fertilization industry, which may even arrive — thanks to the application of biotechnologies — at directly fixing nitrogen in plants, or the case of chemical pesticides used in agriculture, which are being increasingly replaced by forms of integrated pest management.

These changes go much deeper than those predicted in the 1960s and '70s, when the advent of a "service society" was forecast. It is still industry itself that lies at the centre of this change, but in order for new goods and services to be produced they now require efficient, flexible, market-oriented organizations massively equipped with all of those means typical of large industrial companies. For example, the design and development of software are carried out by companies having a typically industrial structure, but which supply totally immaterial goods. The current barriers separating industry, services, and agriculture are becoming less and less distinct, and the most probable outcome will be their disappearance.

New technologies make us question any solution, product or consolidated way of working and organizing. Extraordinary opportunities appear and creative, entrepreneurial forces are set loose.

For example, this allows traditional industries to renovate themselves to respond to new, different market demands. This is not simply a matter of expanding the maturity of sectors and products, but rather becoming innovative once again and promoting innovation in other sectors. The ageing process derives solely from an inability to innovate, and new technological developments know no limits, since they are applied universally. Companies unable to grasp the importance of innovative changes will sooner or later be inexorably pushed out of the market.

This explains why an industry can be mature and static in one country and highly innovative in another. For example, construction sites are still heavily rigid in Europe, while this sector is flexible and innovative in Japan, South Korea and even Brazil. Iron metallurgy — considered a classical example of a mature sector — is under continuous, innovative evolution in Japan, where new methods and products (such as pipes that can resist extremely low temperatures and thin steels) are associated with a highly advanced automation process. This also explains why certain areas specialized in an industrial activity are able to renew themselves vigorously. For exam-

ple, in Italy, the areas outside the "industrial triangle" are now at the forefront in applying new technologies. In regions such as Veneto, Emilia-Romagna, Toscana, Marche and Puglie — with strong cultural roots linked to crafts and agriculture — decentralized, strongly innovative and highly entrepreneurial industrial systems have been developed.

Until a few years ago, investments were identified with physical structures, machines, means, but in a dematerializing society intangible investments take on greater importance. High technology firms already spend more in intangible investments (science and technology, education and training, information, design, development, software) than in traditional capital investments.

These new investments are essential. Since the necessary technologies, knowledge and skills are destined to change and vary rapidly, it is necessary to make sure that new ones are always available, that specialists can promptly acquire new skills and that generalists can keep constantly up to date.

Accumulated knowledge can thus no longer be considered a "stock" from which concepts can be taken when needed (as is occurring for resources), but are instead merely instruments for creating new knowledge to deal with the problems facing mankind.

While economic growth, technological innovation, and the development of culture and society may appear to be quite different from one another — and in some cases may even seem to be in contrast — and involve different operators and interests, have actually always advanced in synchrony, sustaining one another symbiotically.

We can see how the development of thought and the arts has developed along with the economy, science (such as geometry, astronomy, arithmetic), technologies (from materials to construction, engineering, hydraulics, crafts), and the organization of services (laws, transportation, communications, banks).

Science and technology have thus always been essential aspects of culture. Today the explosion of technologies, the variety of options, the technological pluralism that derives from them, the growing weight of quality, all give us an idea of how fundamental the technology–culture link really is. Even more so if we recall that culture is most of all changed due to the enrichment and diffusion of new thoughts, new knowledge and new experiences, to experimentation, creativity, imagination and man's ability to reason.

The truly new aspect of the transformations currently underway is the development of a culture of change, whose most powerful vehicle of diffusion lies in the information technology tools.

Another aspect of the technology–culture link is the growing attention to the market, with a prompt and continuous feedback between users and manufacturers — facilitated by flexible manufacturing systems — and the increasingly fundamental role taken on by the aesthetic and fashion aspects of design, not only for those products (such as clothing and furniture) that have traditionally made use of them, but increasingly for other goods, including machines and tools.

This situation is not merely a question of overlapping, but actual simultaneous penetration of technology and industrial design, often at the highest technical–scientific level, which revolutionizes products, market approach, organization. For example, products that use microprocessors — such as desk or pocket calculators, radios and audio equipment, fax machines, video, and many other consumer electronics products — also see their life-span dramatically reduced. Thus a fax model today lasts no more than four months, and audio modules only six months. Managing this rapid turnover time has become the key element for survival in this industry. Against such a challenge, companies must increasingly behave as though they belonged to the fashion industry.

The analysis carried out thus far indicates that the change we are experiencing is not only "physical", but also and especially "conceptual". We are shifting from a mechanical (or mechanistic) society to a cybernetic society. While in the former, man developed increasingly sophisticated tools, aimed at simulating and expanding the capacity of his arts, muscles, and senses, in the latter these instruments contain more and more intelligence and interactive capability. The concepts of cause-and-effect, sequence, linearity, and hierarchy are replaced with those of functional interdependence; thus, for example, design, production and market can increasingly be considered a single system in constant dialogue, which adjusts itself without friction and delays, and which to this end abandons rigidly fixed and sequential structures so that it can instead choose the most convenient solutions and paths from time to time.

Replacing mechanical systems and connection procedures with telematic ones is destined to bring about enormous changes in the organization of labour and society, and in the behaviour of individuals and groups. The new technologies are upsetting manufacturing systems, the concept of factory and company (born during the Industrial Revolution). The concept of "boundaries" of factories and companies, which in the past could be defined with precision in physical terms (walls, buildings, employees) is less clear

today (consider subsidiary services and the activities performed by other firms), and will virtually disappear in the future when physical connections (halls, roads, railways, mail) will be increasingly replaced by telematic connections, and the factory and company will become "diluted".

Technological evolution affects the quality of industrial products in a differentiated manner as well.

If we observe changes over time in the qualitative characteristics of industrially obtained products, we can note a sharp increase in both absolute and relative terms. Thus if we consider steel and special steels with features that satisfy the heightened needs of the applications for which they are to be used, the qualitative properties of steels (stainless, hard, flexible, rapid, alloyed and others) can be judged greatly superior to those of common steels; this result of technology represents an improvement both in strictly business terms and for its effects on society.

Even for nearly all non-ferrous metals such as aluminium, nickel, titanium, tungsten, magnesium and their alloys, improving their qualitative characteristics has made it possible to use them where it was impossible ten years ago. Other materials such as those for construction (glass, cement, ceramics) have undergone considerable qualitative improvements, with results similar to those mentioned above for metals.

Again, all elastomers, plastomers, and synthetic fibres have been considerably improved in quality over the last twenty years, greatly due to increased knowledge and purification techniques for the original raw materials and polymerization processes, which have made it possible to increase the number of products obtained — diversifying them — in addition to developing existing products. This will continue to intensify in the future. In the sector of inorganic intermediate products, such as sulphuric acid, soda, hydrochloric acid, we can consider that their quality will remain substantially stable over time, as a consequence of the scarce technological evolution in the respective sectors.

On the contrary, we can state that the qualitative characteristics of finished products have often worsened, even though higher-quality materials are increasingly used in their manufacture: this is the case of automobiles and appliances in the last ten years. This statement holds especially true for the shorter physical duration of these items, due to the various technical solutions used, even when accompanied by better materials as stated above. Although a more widespread use of plastics in automobiles has, on the one hand, solved problems for mass production, it has also weakened the parts

in questions and made automobiles lighter, and thus less resistant and safe. The use of light materials and the increased specific power of engines have improved speed and acceleration, but their resistance and duration have diminished. Similar considerations may be made for refrigerators, cookers, washing machines, vacuum cleaners and floor polishers. To complete our analysis, we might add that most agricultural-food products (grain, beets, corn, potatoes, vegetables and fruit) and agricultural-industrial products (cotton, wool, linen, natural rubber, cellulose) slowly tend to increase in quality.

We must remember, however, that in determining the quality of agricultural food products we include the composition and hygiene of the product; while no significant changes can be noted for the former, we can instead notice a decline for the latter caused by the treatments commonly carried out on crops during the growth cycle: we are referring to the effects of pesticides.

For some industrially produced foods there has also been a decline in quality. The need to make foods available even over a considerable space in terms of place and time requires the use of "processing" and "treatments" previously unknown or not used, which in any case reduce the taste, nutritional and often even hygienic aspects. This can be found especially in preserved products, both animal and vegetable, and even in conversion productions, perhaps with the exception of frozen foods.

One final consideration: the above tendencies can be found, though to different degrees, in all industrialized countries, in spite of widely different political and economic systems: in Italy as in France, Germany, United States, the former Soviet Union, Poland, Czechoslovakia, Japan.

This fact may be attributed to a standardized process caused by the diffusion and generalization of manufacturing techniques throughout the world.

7.4. EFFECTS ON ECONOMIC SYSTEMS

The substantial difference between technological innovation or change and their diffusion lies in the fact that the former appear and produce their effects within the company, while the latter directly affects the overall economy. One must bear in mind that innovation is a typically entrepreneurial act, and that technological change satisfies the needs of a certain management criterion; its effects are thus felt directly by the business, while it only indirectly

influences the entire economic system, through its diffusion. It is by shifting from a process of change to a process of diffusion that technology has the effects that can be translated into intense economic progress. Diffusion is thus the means by which technological consequences become meaningful for the entire economic system. From this standpoint, the effects on increased productivity, diminished manufacturing costs and income appear as a whole, repeating, multiplying and expanding from sector to sector, and finally generating progress for the economy. The change grants the innovating company considerable advantages over the others; with diffusion, these advantages have repercussions on the entire production system.

That said, we must observe that the dynamics of diffusion differ in intensity from those of innovation and change. Until 1974 — thus before the beginning of the current technological revolution — the average period of time necessary for a technology to spread was surprisingly long, at least with respect to the speed of innovation by leading companies, both European and American.

Salter's observations (1960) of the various productive branches of British and U.S. industries, for example, show how the productivity interval of plants was such that in the brick sector (United Kingdom), over equal time, the production of the most technologically advanced was in a ratio of 4 to 1 with respect to less-efficient plants; 2 to 1 in the construction sector (U.K.); 1.7 to 1 in footwear (U.K.), 3.5 to 1 in the cement industry (U.S.); 3 to 1 in sugar (U.S.). This clearly shows "that the learning process that lies at the foundation of each episode of technological diffusion is a slow process, which requires considerable amounts of time and resources both to understand it and to apply it in practice". Other factors, both inside and outside imitating companies, also contribute to slowing down the diffusion process. External factors range from institutional limitations (patents, licences) to the natural secrecy of those who productively use the most advanced technology, to difficulties in finding capital.

Internal factors mainly concern management criteria and resistance by company employees (including manual workers and engineers, clerks and executives) to the introduction of new technologies into manufacturing processes or products. For the former, we refer to the mistaken but widespread conviction that amortized plants can manufacture more economically. This represents a reason for delaying technological diffusion, since investments do not merely represent the need to replace worn out plants, but are most of all a vehicle for technical progress. As far as employee resis-

tance to the introduction of new manufacturing techniques is concerned, this introduction often implies in itself a related, negative social effect: technological unemployment. Thus resistance not only by the workforce but also by management is obvious, since both are faced with problems of retraining, redefining roles and duties, if not defending their own jobs, that are often difficult to solve. These factors therefore have and will continue to operate to slow down the diffusion of technical progress. The generalized use of significant technological changes has even been delayed for decades in some instances. Thus innovation and change, from a macroeconomic standpoint, represent only the condition — at times even far off in time — for increases in productivity, as the latter predominantly depends on a generalized use of the findings of technical progress.

The processes of diffusion vary from sector to sector as their technological dynamics change, so that diffusion will be more easily found where the processes of technological change are replaced more slowly, while on the contrary, as the replacement speed picks up, diffusion will be less likely to be generalized. This is especially true considering that technical progress is, for many industrial sectors, subject to limitations set by specialized machinery and plant size. This is true in general, but exceptions do exist. In the ceramics industry around Sassuolo (Italy), for example, generalized diffusion coexists with a high rate of technological change. This also depends on special factors, such as relative accessibility to the most advanced technology, technical application that is economically convenient even for small- and medium-sized companies, the international dimension of the globally controlled market, etc.

From 1975-80, while the innovative process remained rapid, the diffusion process also accelerated in many branches, as pressure gradually increased due to the turbulence of demand and, consequently, the needs of excessive competitiveness.

Two phenomena can now be pointed out that strictly depend on the intrinsic features of many technologies and diffusion dynamics: the onset of induced and interdependent technologies, and technological unemployment.

Currently, all industrialized countries have a strongly integrated economic structure, meaning that the branches of economic activity are highly interdependent.

In other words, a production sector that uses a certain set of plants and other means in order to produce a certain type of goods must have not only the labour factor, but also other goods deriving from other sectors. What is

more, the same manufacturing sector may deliver all or part of its production not to the end user but to other sectors, thus only indirectly satisfying consumer needs.

There is therefore a considerable number of links among the various manufacturing sectors themselves and between them and the various types of related demand.

Leontief's economic theory of sector interdependence already allows us to see not only how the economic–productive situation in a country is and how it is changing, but especially how it may change in the future as a consequence of choices different from those made thus far.

Leontief's intersectorial input–output analysis (1968) tends to highlight the relationships among all sectors of a national economy, and in other words the flows of goods and services among sectors. It is used to analyze and measure the links between the various manufacturing and consumer sectors.

An interdependent and integrated structure offers advantages and disadvantages: among the former, external production economies and the efficiency of the manufacturing system; among the latter, its "rigidity".

System efficiency is present since each company tends to optimize itself in relation to all of the others with which it interacts; thus a true economic functionality occurs between branches and companies.

On the other hand, however, the consequent rigidity prevents companies to adapt independently and rapidly in times of economic crisis; this adaptation may refer either to the type of product, the technologies and production scale, or to employment.

The other significant effect of technological dynamics, in its many facets, is so-called technological unemployment, a direct consequence of the introduction of increasingly automated manufacturing systems, which continually shifts the capital/labour ratio towards capital, to the detriment of labour.

The effects of technology on employment levels are considered typically economic, but at the same time, machines introduced into manufacturing processes create other effects which, while also having an economic influence, are considered mainly social.

However, the simultaneous presence of economic and social aspects is obvious in reference to employment.

From this standpoint it is best to consider the problems related to:

- the rigidity of entry to and exit from the work force;
- transformations in the employment structure;

– changes in the professional aptitude of employees;
– changes in working conditions.

Concerning the first aspect, we should recall that the rigidity of movement within the work force has greatly increased following the constitution of highly interdependent and integrated manufacturing structures, the adoption of increasingly complex and advanced technologies and the growth of company size. Since nearly all branches of activity have reached the saturation point, the crystallization of the employed work force has been reinforced.

With reference to the structure of employment, technology itself — in its strong evolution — has substantially altered the employment structure in industrialized countries.

Until the '70s, this change consisted in a drastic reduction in the population employed in agriculture, and a corresponding increase in employment in industry and, to a lesser degree, services.

Forthcoming changes will certainly consist in a reduced amount of the population employed by industry and an increase in services, or at least in industrial and advanced services.

For the third aspect, we must emphasize that increased specialization of machines used in processes has and will continue to require increasing professional skills by employees, both manual labour and intellectual, in order for productivity to increase.

This should bring about a consequent increase in average education; while this has, in part, already occurred, it is also true that it has been concrete only for very limited aspects. This fact may be considered positive from a strictly professional standpoint, but negative from a social point of view.

With the creation of a society based on information, the communication revolution is already causing a series of social changes; thus the most important effect of new computer science is a considerable increase in productivity, which will be all the more rapid the faster technological innovation is adopted in the work world. The effects of these changes, in terms of professionalism and employment, will be considerable, especially for office workers: while in automating manufacturing processes the massive use of computers is necessarily combined with the use of evolved machine tools and robots, in office work the raw material is solely information.

7.5. EFFECTS ON THE ECONOMIC SIGNIFICANCE OF COMMODITIES AND PURCHASING POWER

The different economic significance of all raw materials, the cost of labour and equipment has led, over time, to a different economic significance/importance of many common, durable and consumer goods. One of the parameters that allow us to make this statement is the relationship between the price of some goods and the annual average per-capita income, and the annual average per-capita wage rate, at current values. These ratios have been calculated in various years (1963, 1973, 1983 and 1993) for various products, for Italy, France, Germany and Great Britain.

The choice of years in which to refer to prices was conditioned by the historical landmark of 1973, the end of the era of cheap, low-priced petroleum, which had influenced and encouraged the success of the first industrial revolution, with large-scale productions and the relative rigid manufacturing and assembly technologies.

In 1963 we were in the most intensive stage of this type of industrialization; after 1973, we witnessed the new stage of industrialization, with high petroleum prices and a progressive replacement of old, rigid manufacturing systems for new, completely different and flexible ones, which required increasing amounts of non-material inputs, at the various stages.

The choice of products was based on their diffusion and economic importance; since no product has such a long life-span to last beyond a decade, we had to consider the prices of products with equivalent performance levels.

Table 7.1 provides some very interesting information, concerning the situation in Italy, which is highly significant and typical of the entire industrialized world. Tables 7.2, 7.3 and 7.4 report the data refered to France, Germany and Great Britain, but limited to automobiles, since it was not possible to find the data for all other goods.

Different trends for the various categories of durable goods considered can be identified:

- Automobiles and motorcycles: the initial stage of decreasing prices in relation to income from 1963 to 1973 was followed by a relatively stable phase from 1973 to 1983.

  The decreasing stage was the result of the effects of a high increase in productivity in assembly plants; the stable phase was the result of the

TABLE 7.1. Current prices of several goods sold in Italy in different years and their percent incidence on the respective annual average per-capita income (1963: Lire 691,000; 1973: Lire 1,767,000; 1983: Lire 11,145,000; 1993: Lire 27,162,000) and the annual average per-capita wage rate (1963: Lire 703,000; 1973: Lire 1,976,000; 1983: Lire 11,979,000; 1993: Lire 24,276,000)

Product	Year	Market price (Italian Lire)	Ratio between prices and annual average per-capita income (%)	Ratio between prices and annual average per-capita wage rate (%)
Cars				
Fiat 500	1963	480,000	69.5	68.3
	1973	699,000	39.6	35.4
Fiat 126	1973	840,000	47.5	42.5
	1983	5,059,000	45.4	42.2
New Fiat 500	1993	9,933,000	36.6	40.9
Fiat 600	1963	640,000	92.6	91.0
Fiat 127	1973	1,068,000	60.4	54.0
	1983	7,441,000	66.8	62.1
Fiat Uno (1000)	1983	8,329,000	74.7	69.5
	1993	13,634,000	50.2	56.2
Fiat Punto (1100)	1993	14,500,000	53.4	59.7
Fiat 124 (1200)	1973	1,418,000	80.2	71.8
Fiat Regata (1300)	1983	11,383,000	102.1	95.0
Fiat Tempra (1400)	1993	21,159,000	77.9	87.2
Fiat 1800	1963	1,545,000	223.6	219.8
Fiat 132 (1800)	1973	1,980,000	112.1	100.2
Fiat Argenta (2000)	1983	17,053,000	153.0	142.4
Fiat Croma (2000)	1993	29,888,000	110.0	123.1
Alfa Romeo	1963	1,300,000	188.1	184.9
Giulietta (1300)	1973	1,870,000	105.8	94.6
	1983	12,730,000	114.2	106.3
Alfa 33	1993	18,478,000	68.0	76.1
Lancia Flavia (1500)	1963	1,800,000	260.5	256.0
Lancia Beta (1600)	1973	2,576,000	145.8	130.4
Lancia Prisma (1600)	1983	15,060,000	135.1	125.7
Lancia Dedra (1600)	1993	24,870,000	91.6	102.4

Source: annual average per-capita income and wage rate: OECD, Economic Outlook, vol. 58, n. 2, 1995. Magazine *Quattroruote*; Annuario Statistico Camera di Commercio di Modena, respective years.

TABLE 7.1. Current prices of several goods sold in Italy in different years and their percent incidence on the respective annual average per-capita income and wage rate (*continued*)

Product	Year	Market price (Italian Lire)	Ratio between prices and annual average per-capita income (%)	Ratio between prices and annual average per-capita wage rate (%)
Citroën 2cv	1963	750,000	108.5	106.7
	1973	933,000	52.8	47.2
	1983	5,963,000	53.5	49.7
Renault R/4 (850)	1963	750,000	108.5	106.7
	1973	918,000	52.0	46.5
	1983	6,400,000	57.4	53.4
	1993	10,500,000	38.7	43.3
BMW 1500	1963	1,910,000	276.4	271.7
BMW 1600	1973	2,263,000	128.1	114.5
BMW 316 (1600)	1983	14,760,000	132.4	123.2
	1993	35,980,000	132.5	148.2
Ford Fiesta (1100)	1983	8,660,000	77.7	72.3
	1993	14,558,000	53.6	60.0
Mercedes 200	1963	2,500,000	361.8	355.6
	1973	3,274,000	185.3	165.7
	1983	19,140,000	171.7	159.8
Mercedes 200 E	1993	54,934,000	202.2	226.3
Opel Kadett (1000)	1963	975,000	141.1	138.7
	1973	1,058,000	59.9	53.5
Opel Kadett (1200)	1983	9,170,000	82.3	76.6
Opel Astra (1400)	1993	20,350,000	74.9	83.8
Volkswagen Beetle (1200)	1963	920,000	133.1	130.9
	1973	1,105,000	62.5	55.9
	1983	6,600,000	59.2	55.1
Volkswagen Beetle (1600)	1993	15,000,000	55.2	61.8
Volkswagen Golf (1300)	1983	9,630,000	86.4	80.4
	1993	20,073,000	73.9	82.7
Motorcycles				
Piaggio Vespa 125 PR/PK	1963	120,000	17.4	17.1
	1973	223,000	12.6	11.3
	1983	1,452,000	13.0	12.1
	1993	3,690,000	13.6	15.2

TABLE 7.1. Current prices of several goods sold in Italy in different years and their percent incidence on the respective annual average per-capita income and wage rate (*continued*)

Product	Year	Market price (Italian Lire)	Ratio between prices and annual average per-capita income (%)	Ratio between prices and annual average per-capita wage rate (%)
Ducati 350 Sport	1983	3,917,000	35.1	32.7
	1993	8,170,000	30.1	33.7
Electric Appliances				
Ignis 275 litre two doors refrigerator	1963	88,000	12.7	12.5
	1973	163,000	9.2	8.2
	1983	456,000	4.1	3.8
Ignis 250 litre two doors refrigerator	1993	500,000	1.8	2.1
Ignis 4 burner gas cooker	1963	110,000	15.9	15.6
	1973	90,000	5.1	4.6
	1983	280,000	2.5	2.3
	1993	380,000	1.4	1.6
Ignis dishwasher 6/8 people	1963	310,000	44.9	44.1
	1973	195,000	11.0	9.9
	1983	698,000	6.3	5.8
	1993	850,000	3.1	3.5
Ignis 5 kg washing machine	1963	189,000	27.4	26.9
	1973	175,000	9.9	8.9
	1983	580,000	5.2	4.8
	1993	580,000	2.1	2.4
Philips electric shaver	1963	12,875	1.9	1.8
	1973	16,500	0.9	0.8
	1983	76,600	0.7	0.6
	1993	131,800	0.5	0.5
Philips 24" black and white television set	1963	190,000	27.5	27.0
	1973	230,000	13.0	11.6
	1983	390,000	3.5	3.3
Philips 24" colour television set	1983	1,000,000	9.0	8.3
	1993	850,000	3.1	3.5
Clothes				
Man's winter wool suit italian size 50 (UK 42") (average quality)	1963	30,000	4.3	4.3
	1973	60,000	3.4	3.0
	1983	250,000	2.2	2.1
	1993	450,000	1.7	1.9

TABLE 7.1. Current prices of several goods sold in Italy in different years and their percent incidence on the respective annual average per-capita income and wage rate (*continued*)

Product	Year	Market price (Italian Lire)	Ratio between prices and annual average per-capita income (%)	Ratio between prices and annual average per-capita wage rate (%)
Woman's winter wool costume (average quality)	1963	20,000	2.9	2.8
	1973	43,700	2.5	2.2
	1983	194,000	1.7	1.6
	1993	410,000	1.5	1.7
Man's rain coat Italian size 50 (UK 42") (average quality)	1963	18,500	2.7	2.6
	1973	38,000	2.2	1.9
	1983	155,000	1.4	1.3
	1993	355,700	1.3	1.5
Man's leather shoes Italian size 43 (UK 9") (average quality)	1963	10,000	1.5	1.4
	1973	19,000	1.1	1.0
	1983	95,000	0.9	0.8
	1993	180,000	0.7	0.7
Office equipment				
Olivetti typewriter model Tecne 3/46	1963	240,000	34.7	34.1
	1973	360,000	20.4	18.2
Olivetti typewriter model Editor 4/46	1983	2,200,000	19.7	18.4
	1993	2,830,000	10.4	11.7
8 MHz Personal computer	1983	4,400,000	39.5	36.7
486/50 MHz Personal computer	1993	3,640,000	13.4	15.0
Industrial vehicles				
Fiat 690 (or 691) truck	1963	6,110,000	884.2	869.1
	1973	11,505,000	651.1	582.2
	1983	97,210,000	872.2	811.5
Fiat 150 Eurocargo E23 truck	1993	128,000,000	471.2	527.3
Fiat 50 HP belt tractor	1963	2,200,000	318.4	312.9
	1973	3,025,000	171.2	153.1
	1983	16,600,000	148.9	138.6
Fiat 50 HP belt tractor	1993	42,000,000	154.6	173.0

TABLE 7.2. Current prices of several goods (cars) sold in France in different years and their percent incidence on the respective annual average per-capita income (1963: FFR 8,575; 1973: FFr 21,681; 1983: FFR 73,140; 1993: FFR 122,826) and the annual average per-capita wage rate (1963: not available data; 1973: FFR 25,344; 1983: FFR 88,253; 1993: FFR 137,827)

Product	Year	Market price (FFR)	Ratio between prices and annual average per-capita income (%)	Ratio between prices and annual average per-capita wage rate (%)
Cars				
Fiat 500	1963	4,500	52.5	-
Fiat 126	1973	8,970	41.4	35.4
	1983	21,950	30.0	24.9
New Fiat 500	1993	45,500	37.0	33.0
Fiat 131 (1300)	1983	45,000	61.5	51.0
Fiat Tempra (1400)	1993	73,600	59.9	53.4
Fiat 1800	1963	13,500	157.4	-
Fiat 132 (1800)	1973	17,760	81.9	70.1
Fiat Argenta (2000)	1983	59,900	81.9	67.9
Fiat Croma (2000)	1993	125,036	101.8	90.7
Alfa Romeo	1963	17,500	204.1	-
Giulietta (1300)	1973	22,900	105.6	90.4
Alfa 33	1983	58,537	80.0	66.3
	1993	77,900	63.4	56.5
Citroën 2cv	1963	5,100	59.5	-
	1973	8,220	37.9	32.4
	1983	28,280	38.7	32.0
Renault R/4 (850)	1963	5,350	62.4	-
	1973	8,900	41.0	35.1
	1983	29,800	40.7	33.8
Renault Twingo (1200)	1993	55,000	44.8	39.9
BMW 1500	1963	16,800	195.9	-
BMW 1600	1973	22,700	104,7	89,6
BMW 316 (1600)	1983	75,060	102.6	85.1
	1993	134,900	109.8	97.9
Mercedes 200	1963	19,100	222.7	-
	1973	32,500	149.9	128.2
	1983	100,600	137.5	114.0

Source: *Autoplus*, respective years

TABLE 7.2. Current prices of several goods (cars) sold in France in different years and their percent incidence on the respective annual average per-capita income and wage rate *(continued)*

Product	Year	Market price (FFR)	Ratio between prices and annual average per-capita income (%)	Ratio between prices and annual average per-capita wage rate (%)
Mercedes 200 E	1993	184,100	149.9	133.6
Opel Kadett (1000)	1963	7,250	84.5	-
	1973	11,560	53.3	45.6
Opel Kadett (1200)	1983	43,555	59.6	49.4
Opel Astra (1400)	1993	72,000	58.6	52.2
Volkswagen Beetle	1963	6,950	81.0	-
(1200)	1973	9,870	45.5	38.9
Volkswagen Golf (1300)	1983	48,200	65.9	54.6
	1993	74,200	60.4	53.8

increasing cost of factors that was out of proportion with respect to that of productivity, in the same plants, and a corresponding increase of income and salaries.

The third stage, from 1983 to 1993, is distinguished by a further reduction; this can be explained by the features of the new technologies rapidly introduced in all industrialized countries, flexible but with high production efficiency.

This tendency occurred also in the French, German and British automobile industry, of course, with different absolute and relative data.

– Industrial vehicles: the same trends noted in the field of automobiles can be seen in trucks and tractors for agriculture, obviously with different, more accentuated values.

– Household appliances: the price of refrigerators, gas cookers, dishwashers, clothes washers and televisions, with respect to average per capita income, have decreased constantly since 1963.

This means that the increase in the factor cost after 1973 was less than the increase in productivity, both with the previous assembly systems and with the new technologies.

TABLE 7.3. Current prices of several goods (cars) sold in Germany in different years and their percent incidence on the respective annual average per-capita income (1963: DM 6,666; 1973: DM 14,800; 1983: DM 27,165; 1993: DM 38,858) and the annual average per-capita wage rate (1963: DM 7,426; 1973: DM 17,219; 1983: DM 31,031; 1993: DM 42,573)

Product	Year	Market price (DM)	Ratio between prices and annual average per-capita income (%)	Ratio between prices and annual average per-capita wage rate (%)
Cars				
Fiat 500	1963	3,190	47.9	43.0
	1973	4,390	29.7	25.5
Fiat 126	1983	7,990	29.4	25.7
New Fiat 500	1993	13,350	34.4	31.8
Fiat 1800	1963	8,990	134.9	121.1
Fiat 132 (1800)	1973	11,480	77.6	66.7
Fiat Argenta (2000)	1983	21.136	77.8	68.1
Fiat Croma (2000)	1993	33,000	84.9	77.5
Alfa Romeo	1963	9,700	145.5	130.6
Giulietta (1300)	1973	11,990	81.0	69.6
	1983	17,770	65.4	57.3
Alfa 33	1993	23,750	61.1	55.8
Citroën 2cv	1963	4,090	61.4	55.1
	1973	4,788	32.4	27.8
	1983	8,495	31.3	27.4
Renault R/4 (850)	1963	4,090	61.4	55.1
	1973	5,545	37.5	32.2
	1983	9,300	34.2	30.0
BMW 1500	1963	8,490	127.4	114.3
BMW 1600	1973	11,280	76.2	65.5
BMW 316 (1600)	1983	18,650	68.7	60.1
	1993	33,500	86.2	78.7
Mercedes 200	1963	12,160	182.4	163.7
	1973	14,541	98.2	84.4
	1983	24,881	91.6	80.2
Mercedes 200 E	1993	46,460	119.6	109.1
Opel Kadett (1000)	1963	5,075	76.1	68.3
	1973	6,910	46.7	40.1
Opel Kadett (1200)	1983	13,535	49.8	43.6

Source: *Auto Motor und Sport*, respective years

TABLE 7.3. Current prices of several goods (cars) sold in Germany in different years and their percent incidence on the respective annual average per-capita income and wage rate (*continued*)

Product	Year	Market price (DM)	Ratio between prices and annual average per-capita income (%)	Ratio between prices and annual average per-capita wage rate (%)
Opel Astra (1400)	1993	21,900	56.4	51.4
Volkswagen Beetle (1200)	1963	4,980	74.7	67.1
	1973	5,650	38.2	32.8
	1983	9,480	34.9	30.6
Volkswagen Golf (1300)	1983	12,442	45.8	40.1
	1993	19,920	51.3	46.8

– Office equipment: the trends are the same as for household appliances.
– Clothing: the trend has been constantly decreasing.

The above considerations are quite indicative of the role of technology on the economic importance of fundamental products, and of changes which are undergoing over time, in the industrialized countries.

7.6. EFFECTS ON ECOLOGICAL SYSTEMS

Economic development, as it has been understood thus far, does increase income and standard of living, but also brings about a number of problems for the ecosystem — some temporary, some permanent.

Many have hypothesized disastrous consequences due to current tendencies to use natural resources and technology indiscriminately; a group of scholars from the Massachusetts Institute of Technology has even produced a development model based on current tendencies and through this model estimated a world-wide collapse around 2020–2050, which could lead humanity to the brink of total catastrophe. The suppositions upon which these researchers based their study are probably pessimistic, but the problem remains and must be dealt with at the source.

In order to provide an objective response, unconditioned by distortions caused by a lack of awareness of the true facts, for this problem it is neces-

TABLE 7.4. Current prices of several goods (cars) sold in Great Britain in different years and their percent incidence on the respective annual average per-capita income (1963: £st 570; 1973: £st 1,321; 1983: £st 5,400; 1993: £st 10,839) and the annual average per-capita wage rate (1963: £st 727; 1973: £st 1,703; 1983: £st 6,617; 1993: £st 13,605).

Product	Year	Market price (*£st*)	Ratio between prices and annual average per-capita income (%)	Ratio between prices and annual average per-capita wage rate (%)
Cars				
Fiat 500	1963	411	72.1	56.5
	1973	598	45.3	35.1
Fiat 126	1983	2,245	41.6	33.9
New Fiat 500	1993	4,990	46.0	36.7
Fiat 1800	1963	1,148	201.4	157.9
Fiat 132 (1800)	1973	1,722	130.4	101.1
Fiat Argenta (2000)	1983	6,345	117.5	95.9
Fiat Croma (2000)	1993	12,331	113.8	90.6
Alfa Romeo	1963	1,283	225.1	176.5
Giulietta (1300)	1973	1,826	138.2	107.2
	1983	5,650	104.6	85.4
Alfa 33	1993	9,807	90.5	72.1
Citroën 2cv	1963	470	82.5	64.6
	1973	708	53.6	41.6
	1983	2,399	44.4	36.3
Renault R/4 (850)	1963	482	84.6	66.3
	1973	715	54.1	42.0
	1983	3,424	63.4	51.7
Renault 5	1993	5,555	51.3	40.8
BMW 1500	1963	1,376	241.1	189.3
BMW 1600	1973	1,899	143.8	111.5
BMW 316 (1600)	1983	6,250	115.7	94.5
	1993	15,100	139.3	111.0
Mercedes 200	1963	2,280	400.0	313.6
	1973	2,898	219.4	170.2
	1983	9,130	169.1	138.0
Mercedes 200 E	1993	19,910	183.7	146.3
Volkswagen Beetle	1963	625	109.6	86.0
(1200)	1973	866	65.6	50.9
Volkswagen Golf	1983	4,848	89.8	73.3
(1300)	1993	9,179	84.7	67.5

Source: *CAR*, respective years

sary to examine the wastes produced by man's activities and those produced by nature in its continuous evolutionary process and compare them.

Few researchers seem, until now, to have posed the problem in this way, which appears to be the only one capable of answering the question: to what degree do the pollution and environmental changes caused by man affect natural ones?

Only an objective answer allows us to assess whether we are facing global or local problems, irreversible or reversible ones. The choices to be made depend on this answer.

We must proceed systematically, keeping chemical, thermal, and radioactive disturbances separate, as well as those related to the stability of the soil and microclimates.

For disturbances of chemical origin, we must distinguish between those related to substances that already exist in nature and those that do not exist.

This distinction is essential in order to understand a few serious phenomena, some of which have been studied and some are yet unknown, such as the "greenhouse effect" and the "Venus syndrome" (Ciusa, 1976; Smith, 1982; Mallone, 1987; Bolin, 1970; Revelle, 1982).

The greenhouse effect is a phenomenon that leads to increasing global temperatures on Earth, as a consequence of the absorption by atmospheric gases of some of the infrared radiation emitted by the Earth.

The main gas that contributes to this phenomenon is carbon dioxide which, in the last hundred years, has been released into the atmosphere in increasing amounts, parallel to the increase in the use of fossil fuels. Other gases, also produced by man in technological, energy and agricultural processes, contribute to the greenhouse effect to a degree approximately equal to carbon dioxide: these include nitrogen oxides, hydrocarbons, chlorofluorocarbons (CFCs), methane, ozone.

The first concept to introduce in order to better understand the mechanisms that lead to this phenomenon is that of the "energy balance" between incident solar radiation and radiation re-emitted by the earth-atmosphere system (Caira et al., 1989).

Solar radiation, emitted in a spectral range within the visible band (0.3 – 0.7 μm), interacts with the atmosphere in various ways as it enters the earth's system; as a consequence, the energy that reaches the ground is drastically reduced with respect to that arriving from space: if we set incident energy at 100, if the sky is clear then approximately 65% of the radiation reaches the ground, while on a cloudy day the fraction may fall to 50% or lower.

The incoming solar energy is of course re-emitted by the earth's system in an identical amount to the incident energy but, as a consequence of interaction, in a spectral range shifted towards infrared, that is with wavelengths between 5 and 40 μm).

Atmospheric gases are very important in maintaining the complex energy balance of the planet: their presence, at current levels of atmospheric concentration, produces a temporary absorption of approximately 17% of the infrared radiation. This absorption, equivalent to a sort of energy storage, contributes to maintaining the average temperature of the planet.

Since the percentage of "imprisoned" energy varies in proportion to the atmospheric concentration of greenhouse-gases, we can see how a change in this concentration leads to an imbalance in the earth's energy balance and, in particular, how an increased presence of such gases leads to an overall average increase in the temperature of the planet, the much-feared "greenhouse effect" (Oort, 1970).

But let us now see how and why the greenhouse-gases allow radiation to "enter" the earth's system but not to "leave" it.

Each molecule is physically characterized by absorption bands centred around special wavelengths; "greenhouse gases" are defined as all gases that are transparent to radiation in the visible range, thus to the solar light striking the atmosphere while presenting bands of heavy absorption in the infrared range, thus in the wavelengths typical of the earth's emissions.

Since the phenomenon of atomic absorption leading to the greenhouse effect is a conceptually similar process for all greenhouse gases, it is sufficient to provide further details for carbon dioxide alone.

Carbon dioxide, in the range of 5–40 μm where the earth's emissions fall, has a band of heavy absorption centred around 14.7 μm, and two bands of weak absorption centred around 9.4 and 10.4 μm, due to which carbon dioxide is considered to be a strong absorber of the earth's radiant energy.

On the other hand, carbon dioxide is only a weak absorber of incident solar energy since, in the maximum sun emission spectrum between 0 and 2 μm, it has only weak absorption bands (centred around 1.4, 1.6 and 2.0 μm, respectively).

For these characteristics, and in relation to the considerable increase of its atmospheric concentration, carbon dioxide is considered to be the most dangerous of all of the greenhouse gases, alone contributing to 50% of the "greenhouse effect".

The amount of carbon dioxide currently present in the atmosphere is the difference between the flow of the natural cycle, which may be estimated at approximately 85×10^9 t/y, and man's production of the gas, today equal to approximately 10×10^9 t/y.

Man's production of carbon dioxide is in turn the "algebraic" result of combustion and deforestation.

The natural cycle of carbon dioxide involves most natural elements, in constant interchange, both land and sea, living and non.

This dynamic state is mainly due to the capacity — by phytoplankton in the sea, and plant organisms on land — to absorb and use solar energy to transform carbon dioxide into organic molecules. This process is commonly known under the term of chlorophyll photosynthesis.

An approximate assessment indicates that, overall, land vegetation fix an average value of 20–30 billion tons of carbon dioxide per year, in the form of organic compounds.

Some important sources that produce carbon dioxide on land are:

- breathing of all living organisms;
- soil breathing (due to the decomposition of plants and animals, caused by micro-organisms present in the soil; in these reactions, the carbon contained in the animal tissues oxidates and produces carbon dioxide, which returns to the atmosphere);
- volcanic eruptions;
- natural gaseous sources.

The marine biological cycle contributes in turn, and substantially, to absorbing and stabilizing part of the atmosphere's carbon dioxide. According to some authors, the assimilation of carbon dioxide that may be attributed to marine plants — and essentially phytoplankton — is approximately 60% of the total.

Exchanges of carbon dioxide between the ocean and the atmosphere involve a surface layer approximately 100 metres thick, which represents the actual limit for photosynthesis with respect to the entire mass of ocean waters; it has been calculated that phytoplankton assimilates, overall, 40 billion t/y of carbon dioxide dissolved in water, producing oxygen. The maximum amount stabilized each year by these plants is, however, not a constant but varies according to geographical position, ranging from 300 g to 3 kg/m^2, depending on the sea's concentration of phytoplankton.

The carbon dioxide transfer cycle in the sea closes with the assimilation of phytoplankton by zooplankton and fish, and finally the decomposition of

these organisms in the deepest layers of the sea, restoring carbon dioxide in the form of carbonate and bicarbonate ions. Once these ions are produced, they essentially remain in place due to the low water exchange rate between deep sea layers and surface layers.

Unfortunately, in recent years considerable increases in the atmospheric concentration of carbon dioxide have been recorded by weather stations scattered throughout the world, evidence of a planetary imbalance between the sources of absorption and production which regulate the natural cycle of this gas.

Together with the emission of such high amounts, which leads to continuous increases in the atmospheric concentration of carbon dioxide, the phenomenon of deforestation has also greatly increased.

An average deforestation rate between 1 and 2% has been achieved, corresponding to an annual loss of approximately 10–20 million hectares of forest. According to reliable studies, the missing absorption of carbon dioxide corresponding to the destruction of such a vast area means releasing 1–2 billion extra tons of carbon dioxide each year.

The first known measurements regarding atmospheric concentrations of carbon dioxide date from 1860: though affected by considerable fluctuations, probably due to their unsystematic organization, these measurements indicated an increase in the average atmospheric concentration of this gas, which from approximately 290 ppm in 1880 reached 300 ppm in 1900 and 310 and beyond in 1940.

In 1939, it was hypothesized that the increase in carbon dioxide could be related to the heating of the atmosphere which occurred in the same period throughout the world. As a consequence of the debate that arose around the problem, the international scientific community organized a network of measuring stations in the 1950s, extended throughout the globe (Hawaii, Scandinavia, Alaska, Australia and Antarctica), preferring sites without local concentrations of carbon dioxide-producing sources, for the purpose of verifying whether, and how, the concentration of carbon dioxide was changing, and especially whether the phenomenon was truly planetary.

A comparison between the average data gathered at the measuring stations between 1958 and 1978 confirmed the notable increase in the growth of the phenomenon: within this period, the average value of the carbon dioxide concentrations in the atmosphere rose from 315 to over 330 ppm (average annual growth of approximately 0.58 ppm). The perfect agreement not only of the growth rate but also average measurement values taken at

the various stations also confirmed the planetary nature of the situation, and brought the problem of the consequent climatic impact to the attention of public opinion.

On a regional scale, an analysis of the pattern of local concentrations measured at the various stations is quite interesting; all of the curves have an oscillating pattern representative of the seasonal variations in the photosynthesis of the vegetation. The oscillations are characterized, in particular, by variable amplitudes in relation to the influence of latitude on photosynthetic activity, and thus on the concentration of carbon dioxide in the local atmosphere (note that the oscillation values measured in the southern hemisphere, in the Antarctic, are lower than the equatorial values measured in Mauna Loa, Hawaii, due to the reduced extension of biospherically active land area).

The highest values of average annual carbon dioxide concentration were found, however, in the longitudinal band between 40°N and 70°N, corresponding to the most industrialized areas of the planet.

The pattern of the increasing annual carbon dioxide concentration in the atmosphere over the last thirty years is shown in the following table:

Period	ppm	Period	ppm
1958–1963	315.0–318.5	1981–1985	338–343
1963–1968	318.5–322.4	1986–1990	344–348
1968–1973	322.4–329.4	1991–1995	350–355
1973–1980	329.4–337.4		

The considerable growth rate of the phenomenon until the early 1970s is evident; the reversed tendency occurring after 1973 appears to be directly related to the energy crisis that occurred then, and the consequent reduction in the use of fossil fuels.

For some years now, the atmospheric concentration of carbon dioxide has been measured in Italy as well, at the Air Force weather station on Mount Cimone (Modena).

The measurements have shown a constant rise in the average concentration of carbon dioxide, with seasonal variations in 1979 between a maximum of 342 ppm, a minimum of 325 ppm, and an average value of around 333 ppm; in 1986, extreme range values of 352 and 336 ppm and an average value of 343 ppm. The average increase over eight years was approximately 1.25 ppm per year. The typical periodic pattern was found for the concentra-

tion, with a maximum in the winter months and a minimum in the summer. The winter peak can be explained by three coinciding factors: man's contribution of carbon dioxide "carried" by the winds which mainly come, during that period, from Northern Europe; the simultaneous increased local production by man, due to the contribution of household heating and, finally, the "minimum" photosynthetic activity related to the annual plant life cycle.

It is also interesting to compare the average monthly concentration measurements of carbon dioxide taken from 1979 to 1983 at the Mauna Loa station (Hawaii) and Mount Cimone: there is a fair agreement on the average growth rate of carbon dioxide levels in the atmosphere, while on the contrary there is a considerable difference in the amplitude of period oscillations around the average value, typical of the different latitude where the measurements were taken.

In order to have a broad overview, we must refer to other delicate polluting factors such as carbon monoxide, dust, sulphur dioxide, nitrogen oxides, heavy metals.

As far as carbon monoxide is concerned, the naturally formed quantity is around 5×10^9 tons, thus approximately 20 times the quantities produced by combustion. But we should emphasize the fact that carbon monoxide not only dissolves in rain and other waters and is absorbed by the ground, is converted into carbon dioxide in the atmosphere one month after its formation, and thus cannot accumulate.

The dust emitted into the atmosphere by all human activity — combustion, construction and other industrial processes — consists of metal dusts and their by-products and earth dusts: approximate calculations show that the quantities emitted total 0.2×10^9 tons per year; of these, 99.9% — due to the dimensions of the particles and thus their weight — fall to earth after a few days and are no longer found in the atmosphere, where 0.1% remains even for a year. On the other hand the erosion of stone, volcanic eruptions, wave motion send at least $3–4 \times 10^9$ tons of dust into the atmosphere, thus more than ten times the quantities produced by human activity.

As far as sulphur is concerned, from an examination of its natural cycle it can be noted that in nature considerable quantities of sulphur oxide are released into the atmosphere and thus significant flows of this substance into the environment: natural sources mainly consist of spontaneous combustion of plant mass, decomposition of organic matter and volcanic eruptions.

It is interesting to compare these flows with artificial flow values caused by human activities (energy-related and other):

SULPHUR OXIDES

Natural flow	15 million tonnes
Anthropogenic flow	100 million tonnes

Even the natural nitrogen cycle includes marked flows of nitrogen oxides, and has specific characteristics in relation to the artificial flow created by man. A comparison between the two flows may be conducted based on the following values:

NITROGEN OXIDES

Natural flow	102 million tonnes
Anthropogenic flow	70 million tonnes

An examination of these data and those for other elements highlights the strong global disturbance caused by human activities in the life cycles of nearly all of the main elements, even those most widespread in nature such as aluminium, and especially some of the most potentially toxic and damaging to the biosphere, such as lead and mercury.

For lead, a strong alteration in the cycle is caused by human activity: against the 18,000 t/y released into the atmosphere by natural processes, human activity released 440,000.

Mercury also shows a flow greatly affected by man-made emissions: 11,000 t/y respect to those of natural origin, equal to 40 t/y.

Part of the gaseous pollutants (sulphur dioxide, nitrogen oxides and carbon monoxide) and particles are deposited, mainly as dry precipitates, as they are, thus without changing in chemical form, within 200–300 kilometres of the source.

The rest of the pollutants falls at greater distances, even a thousand or more kilometres away, after travelling through the atmosphere thanks to winds and diffusion, and after undergoing an intensive chemical alteration which results from a complex series of reactions and mixing processes.

During their long transport through the atmosphere, sulphur dioxide and nitrogen oxides are transformed into sulphates and nitrates or the respective acids, sulphuric and nitric. They fall to the ground far from the source in two ways: dry or wet settling. The remaining part of the emissions of sulphur dioxide and nitrogen oxides are deposited in the form of dry gases, and

some transformation obtained by chemical reactions in the obtained by chemical reactions in the atmospheric gas phase products such as sulphates and nitrates, are deposited in the form of particles. Sulphuric acid and nitric acid, resulting from the chemical transformations that involve the liquid phase of clouds or occur beneath clouds during precipitation are instead deposited in moist form, through precipitation itself (rain, snow or fog).

Ozone and peroxiacetyl nitrate, which are in turn produced by the conversion of hydrocarbons and nitrogen oxides by the ultraviolet radiation from the sun, not only play an important role in acidification but are in themselves highly phytotoxic pollutants, which exert damaging effects on agricultural and forest plants.

The above demonstrates that pollutant gas emissions initiate damaging processes in three main forms: in their original state (sulphur dioxide, nitrogen oxides and carbon monoxide); through their chemical transformation products, such as acids and compounds that generate acids; through ozone and other photochemical oxidants, also deriving from conversion processes.

One of the most obvious and most-discussed aspects of atmospheric pollution is the destruction of forests.

The symptoms are fairly clear, and appear with premature ageing of plants, followed by a deterioration of forest life and the death of the individual plants affected. But the problem that remains open is that of identifying the cause or biological mechanism that causes an entire organism to precipitate so quickly. The way in which the disease appears and progresses leads us to believe that there must be violent impact on the environment and forest ecosystem.

The most accredited hypotheses concern with environmental pollution (acid rain and its direct or indirect effects on the plant through the soil; the effects of specific atmospheric pollutants) and to conditions of chemical or biological stress (together or independent from one another). However, in spite of considerable experimental support, these hypotheses are not exhaustive. In certain environmental conditions acid rains appear to be the main cause of the illness, while in other conditions it appears to be attributed to other causes, such as for example fertilizers, to the point that various hypotheses may be equally convincing.

The hypotheses formulated thus far to explain the destruction of forests are based on five different factors: acid deposits, ozone, ammonium, stress and ionizing radiation originating from nuclear power plants. Other hy-

potheses, such as those that refer to heavy metals, sulphur dioxide and nitrogen oxides can actually be conducted back to the hypotheses cited. Each of the above hypotheses is still being tested and some appear to be convincing, at least on the basis of their theoretical premises. Certainly, the scientific results obtained thus far are still partial, since it has not yet been possible to reproduce the phenomenon entirely.

Negative effects of acid rain also occur on agricultural crops and buildings: an especially important case for our artistic heritage, as highlighted by the plight of Venice and many other Italian historical cities.

One characteristic of acid rain is its transnational nature. The pollution produced in one country is dragged by the wind for hundreds of kilometres and falls in other countries. Given the prevalent wind direction, there are systematic transfers of pollution from one country to another, which have already given rise to international controversies: for example between Canada and the United States, Scandinavian countries and the United Kingdom, countries of Central and Eastern Europe. In this case, the damage is suffered by countries other than those who produce them, and this leads to problems in international relations that are not easy to solve. In addition, not all lands are equally sensitive to acid rain: the damage is greater where the soil is already acid, where there is little turnover, where precipitation is abundant and where there are forests rather than agricultural lands.

Pollution by chemical substances already present in nature is added to that by fully synthetic chemical substances, therefore not present in nature: pesticides, fungicides, anti-parasite treatments, detergents, dyes, fluorohydrocarbons (Freon) or chlorohydrocarbons, and others. These compounds have been manufactured with a great stability over time, and are often highly toxic or in any case harmful to living organisms.

The effects of synthetic detergents and pesticides in water are well known, as well as the accumulation of DDT in animal organisms, these are all compounds that do not break down in the biodegrading action of water. While we point out that their presence has been found only near zones where they have been used — except for DDT, which has been found in significant quantities in large fish and cetaceans, far from the area of use — we should emphasize that their production and consumption are linked to the increase and treatment of agricultural crops for food use and that man's choice — fifty, thirty and twenty years ago — was between immediate and certain famine for hundreds of millions of people and a possible physical damage (intoxication and tumours) for a few thousand.

One phenomenon that is currently the object of observations and studies by the international scientific community is the reduction in the stratospheric ozone caused by nitrogen oxides, but mainly by Freon.

As we know, there is a layer of atmosphere known as the ozone layer at the altitude between 20 and 50 km consisting of high concentrations of ozone with which Freon interacts chemically and destroys it.

The reduction in the ozone layer, which is a huge shield against ultraviolet solar radiation and which regulates the balance of heat in the stratosphere, leads to consequences that then affect the climate and human health.

Currently, the stratospheric ozone present is in a balanced condition (photochemical balance) with greater concentrations in the equatorial (or intertropical) stratosphere and lower concentrations at the poles. Experimental measurements have shown that the difference in concentration between the equator and the poles is much more marked than what can be theoretically calculated on the basis of photochemical balance. Studies conducted have indeed clarified that ozone is actively formed above the equatorial zone and is then constantly carried towards the polar zones by stratospheric winds related to the two permanent cyclone areas, which exist over the two poles (stratospheric polar vortices). During this passage, part of the ozone penetrates into the lower layers of the atmosphere through tears in the tropopause (an atmospheric layer at about 10 km of altitude, which separates the stratosphere from the troposphere). These tears are more or less stationary, but are accentuated by violent intakes of cold air or widespread meteorological disturbances (Farman et al. 1985; Hasebe, 1985; Zarefos and Ghazy, 1984).

Since tears in the tropopause are more marked and frequent near the polar regions (between 60 and 70 degrees of latitude), it often occurs that only very little ozone reaches the polar stratosphere. A good indicator of tears in the tropopause and the consequent penetration by ozone into the troposphere consists of radioactive fallout, and especially ground concentrations of radionuclides such as: Be-7 (beryllium-7), Na-22 (sodium-22) and P-32 (phosphorous-32).

Generally, however, the concentration of ozone should be merely a function of the latitude, at least as an average value over long periods; in truth, there are non-periodic shifts and oscillations, even considerable, whose causes are not as yet fully known.

Some experts believe that the basic cause of changes in the stratospheric ozone layer is related to solar activity, and more specifically the consistency of sunspots.

This hypothesis was confirmed between 1965 and 1976, when the ozone showed first an increase, culminating in 1970, and then a significant decrease until 1976. Since 1970, together with the ozone increase, the sun also showed its greatest sunspot activity and the relationship between sun and ozone appeared even too obvious. Instead some doubts arose, since the decrease in ozone after 1970 was much faster than could be expected for an effect that depended solely on the sun's activity. Then some researchers hypothesized that there must be another cause of the destruction of the ozone layer. Some atmospheric pollutants were identified, the most suspect of which was Freon — already suspected and traced by some laboratory studies — due to its volatility and chemical composition.

But the question of whether or not Freon was harmful, far from being solved, became increasingly open. Doubts were put forward as to the actual reliability of the ozone measurements taken from earth using special spectrometers.

The new and more powerful means of study and research have evidenced that there may be many causes, at times inter-related: they range from astronomical to meteorological factors, from atmospheric physical factors to chemical factors, from natural factors to human factors such as air pollution. In particular, in addition to Freon many chlorine and nitrogen compounds and some organic pollutants have been found, including methane.

The problem is therefore enormously complex and difficult to solve. However, the most common indicative orientation among experts in this field supposes that, in the long term, the main influence on ozone variations comes first of all from solar activity and the variation in incident solar radiation, then from meteorological factors and anomalies in stratospheric circulation, and finally from all of the other factors which may only occasionally become predominant. This order of importance could, however, be overturned in the future if the emission of aeriform pollutants is not slowed down.

With reference to thermal pollution, heat is considered an irreversible disturbing factor and thus very critical.

When transforming and using energy resources, not all of the heat produced can be converted into useful work; part of it is inevitably lost. This produces waste heat. If this occurred to a small degree it would have no influence on the global energy balance of the Earth, and would allow us to ignore the relative problems.

Since global energy consumption is continually increasing in absolute terms, and thus so is waste heat, the worry arises of possible significant changes in the Earth's temperature, both locally and as a general average.

There is an energy balance point between the quantity of radiant energy that the earth absorbs and the amount it projects outward, allowing it to keep the globe's temperature constant.

The earth behaves like a blackbody: it is "a very good absorber and very efficient radiator of heat". Trees, oceans, and so on, all absorb solar energy with great efficiency, providing the Earth with its blackbody properties. And since the physical laws according to which blackbodies behave are well known, we can predict with a certain margin of error how the radiation balance between the sun and earth will be affected if the earth's temperature increases.

If we estimate that in the year 2060 the world's energy consumption will be $2{,}200 \times 10^{12}$ W, and thus the incremental quantity of thermal energy, we can deduce that in order to radiate this incremental energy outward, to maintain the balance of sun–earth energy, the earth will become warmer, because only by becoming warmer can a blackbody radiate more energy. In this case, the earth would have to increase its temperature by 1.5 °C.

Of course, this calculation is made in the hypothesis that no other balancing or amplifying forces come into play.

For radioactive pollution, we should specify that this occurs only in the case of accidents involving equipment that handle uranium or other radioactive materials (nuclear power plants, experimental and military reactors), or following the explosion of nuclear bombs. The handling of such materials is normally subject to extremely high safety levels, which require extremely large investments. Even the removal and confinement of waste, though not completely resolved, are done under conditions that exclude the possibility of radioactive leaks.

Should this occur, radioactive contamination is inevitable for a very long time (even thousands of years); thus a similar event must be strictly prevented, by adopting adequate systems, normally very expensive. It is calculated that the cost of safety systems in a nuclear power plant increases investment costs for the plant by approximately 40%, and the maintenance and operating costs also increase considerably.

There are other types of environmental alterations as well: those due to excavation work and removal of vegetation.

While it is unthinkable to totally eliminate all production activity, the above have undoubtedly been found to be harmful, and not only from a

landscape point of view: in truth, the morphology of the land, microclimates, and even territorial stability are often changed. This is true not only for surface excavations, but also underground ones.

It appears that a number of earthquakes are due to underground settling, caused by "holes" produced by extraction (natural gas, petroleum, etc.).

In addition, radical and rapid environmental changes, often wide-ranging, appear to be attributed to crop changes. One example is the African strip of Sahel, plagued for years by total draught; changes in crop orientations were great with respect to those traditionally and typically planted in the area for centuries.

Since the problem of using wood and cellulose remains, as does that of increasing agricultural food crops, in order to avoid the hazards produced and at the same time satisfy the growing demands of the world community, it is best to adopt immediately those production criteria and measures that make it possible to maintain in a detailed and differentiated manner natural balances within limited variations.

Finally we can conclude that in order to avoid a gradual aggravation of the effects of technology on the ecological system, a modern industrial policy must consider what measures can, if possible, prevent the formation of permanent perturbations by choices appropriate to the various situations.

Chapter 8

METHODS FOR EVALUATING PROCESSES AND TECHNOLOGIES

8.1. FEASIBILITY STUDIES

When deciding to create a new manufacturing activity — and thus an investment — both in the case of a new business and in the transformation of an existing one, it becomes increasingly useful to gather elements, data and indices in order to assess the convenience of a specific choice in advance.

In this stage feasibility studies must be used, obviously if a detailed project is already available, ready for concrete use. These studies make use of different methods which, if carried out accurately and competently, attempt to obtain information truly useful for decision-making, to the point that they have been systematically used for many years by entrepreneurs in the United States, Germany, France and other countries. In addition, since they can be used for projects to be realised internally, but also abroad, they are considered essential by UNIDO, the UN Industrial Development Organization (UNIDO, 1991).

Their use is especially advantageous when there are two or more different projects to compare, even of differing entity, and when information on the convenience to the business and community is required, especially if the chosen production and relative investment are considerable.

Studies and calculations must be interdisciplinary in nature, since the aspects to be dealt with range from those typical of the market to those of evaluating the state of technology, and also estimating costs and benefits (Barbiroli, 1976).

The development cycle of a project may be summarized as follows:

The pre-investment phase includes various stages: identifying the "investment opportunities" (opportunity studies), preliminary selection and definition of projects, project formulation, final assessment and investment decision.

The development cycle of a project is first of all characterized by identifying investment opportunities, if the person does not yet have a clear idea of the investment.

In order to identify to which sector (or sectors) an internal or external production choice — and thus an investment — should be directed, various aspects must be examined:

a) the domestic and international situation of natural resources and raw materials, and their conversion and processing potential;
b) the future demand for such goods according to potential increases in population and income;
c) imports, to identify where they may be replaced;
d) manufacturing sectors favourable in other countries with similar levels of development, capital, labour, resources and economic structure;
e) possible links to other domestic and international industries;
f) the possibility of extending existing processing lines by integration in the same direction (such as a steel production plant with an electric-arc furnace for a steel mill, or a petrochemical industry for a refinery);
g) the possibility of diversification (such as a pharmaceutical company for a petrochemical complex);
h) the possibility of expanding production capacity to achieve economies of scale;
i) the general investment situation;
j) industrial policies;
k) the cost and availability of production factors;
l) export possibilities;
m) the structural features of the area where the initiative is carried out, to identify priority sectors;
n) the state of technology, on a domestic and international level, in the sectors already found to be of interest.

Studies for investment opportunities may be general when one has few ideas as to the initiatives to undertake. However, even in this instance, it is best to outline the field of research either by referring to an area, or a sub-sector, or to a group of resources.

When a basic idea already exists, the opportunity study is certainly more specific, and thus it is easier to provide a positive indication which then makes it possible to create and design a concrete project, to be subjected to a feasibility study.

A feasibility study for a project concept must be divided into various stages:

1) Characteristics and variables of the project.
2) Market and sales.

3) Materials and supplies.
4) Location, site and environment.
5) Engineering and technology.
6) Organization and overhead costs.
7) Human resources.
8) Project implementation schedule.
9) Financial analysis and investment appraisal.

The entrepreneur or person responsible for company decisions finds himself faced with a number of simultaneous and correlated problems, in his attempt to follow the most appropriate economic path, such as: choosing the technology, the products, the technological intensity and the production scale.

a) Technologies and technological intensity.

The choice of process characteristics must be strictly related to the choice of product type: this determines the production coefficients and productivity.

Firstly, the level of maturity of each technology must be considered: new and unproven or experimental techniques should not be considered appropriate in general, obsolescent technology should be avoided, which means that technological trends have to be carefully considered.

The selection of technology has to be related to the principal inputs that may be available for a project and to an appropriate combination of factor resources for both the short and the long term. In certain cases, the raw materials could determine the technology to be used.

A technological process based on local raw materials and inputs may be preferable to one for which the principal inputs have to be imported indefinitely, particularly if serious foreign exchange regulations affect the inflow of such materials.

The degree of *capital intensity* considered appropriate could define the technology parameters. In countries with a shortage of labour, or where labour is very expensive as in Western Europe, capital-intensive techniques may be appropriate and economically justified. In countries with excess labour, labour-saving techniques may prove unnecessarily expensive. This situation may apply to the overall technology as well as to the degree of mechanization of projects or particular production operations such as material-handling. The choices from the viewpoint of both labour and capital should be given in the feasibility study so that the most appropriate technique can be selected.

Undoubtedly, recent years have been characterized by a race towards the use of increasingly advanced, and therefore complex, technologies, using increasingly automated or robotised manufacturing systems.

However, as we have already discussed previously, each technology has a limit of economic convenience in using automated systems; this limit must be predetermined by each company when making choices, in order to achieve maximum productivity at the lowest cost of the goods, even if the search for this limit has led and will continue to lead to the shedding of jobs among the workforce.

On the other hand, there is the dilemma: productivity — high competitiveness — reduced employment versus: maintaining employment — low competitiveness, which may not be solved easily nor rapidly in a post-industrial era.

Alternative technologies should also be evaluated with regard to their environmental impacts. Depending on the type of industry and local environment, critical elements such as economic use of raw materials, low-emission technologies (state of the art) and low-waste-production processes must be considered for the selection of suitable technologies. The evaluation should not be based on the optimization of only one variable target, but should aim at an optimal combination of human, techno-economic and strategic requirements.

b) Production orientation and product mix.

A specific technology has to be viewed in the context of the total product mix that it generates, and if an alternative technology results in a wider product mix, starting from the same basic production materials and inputs, the value of the total mix, including saleable by-products, should be taken into account. The extent to which a particular technology or production technique can be effectively absorbed by a country could influence the choice of technology. It is often suggested that certain technologies are too sophisticated for particular developing countries because of their inadequate *technological absorptive capacity*.

The need to satisfy the specific demands of special market segments requires that the company choose the most advantageous product mix to offer for sale. The difficulties encountered in the choice increase as an effect of differentiation from the products offered by the competition, and in particular due to the supplementary costs created by this differentiation. The problem actually lies in combining the advantages deriving from a vast range of

goods available with increased costs for production, organization and administration that result from this range.

First of all, it can be said that an excessive variety of models and sizes not only causes considerable production and distribution problems, but also leads to dangerous confusion for the consumer at the time of selecting a purchase.

A second basic limitation lies in the topics and themes of the advertising campaign, which often do not allow an equally effective presentation in the case of a range of products that differ widely in conception or presentation.

In order to penetrate more than one market segment, the technique of differentiating quality and prices is often adopted, consisting for example of flanking a low-price product, but with considerable commercial value, with another product higher in quality and price, though it is not logical to predict high sales volumes for the latter. This special technique, known as trading up, tends to increase the overall brand prestige, and partly serves to qualify the first product. On the other hand, there is also the technique of coupling a prestigious product with another product lower in price and quality (trading down), which allows high sales volumes and thus greater profits. The risk of reducing the overall brand prestige should be foreseen in advance and avoided by taking advantage of different distribution channels, or by selling the second product under a different brand name.

The product range may also be expanded without increasing production capacity, but by arranging directly for commercial or distribution integration. This is generally done by purchasing articles from other manufacturers to be sold under one's own trademark. Alongside the main objective of expanding supply, this often allows the advantage of testing a certain product without heavy initial investments, delaying the definitive decision whether to manufacture internally until the market reaction to the product is sufficiently known.

For small companies, on the contrary, the fact of supplying larger ones with products that will be sold under the purchaser's brand name does on the one hand ensure continuity of production and cancel out the costs of distribution and advertising, but on the other also significantly reduces economic and decision-making independence, as well as profit margins.

Frequently, we still encounter a differentiation in quality and price between homogeneous or subsequent products, by adopting so-called minor brands: the essential purpose of this operation often consists of avoiding committing the brand name to the sale of an inferior quality product. It gen-

erally occurs that the same manufacturing structures may be used in production of the second product as for the first, though using more economical materials and technologies, thus achieving further economies from the increased use of the systems.

Finally, we should emphasize that the entire range of products must be critically reviewed on a periodic basis, as occurs for sale prices; indeed, the choices made at a certain time may become inadequate to new needs and may require changes.

If the company is blessed with foresight, and if it is technically possible, it should create conditions of flexibility, so that when the need arises it can adapt the product mix in qualitative-quantitative terms with a minimum increase in costs. Otherwise, the company will find itself having to deal with a restructuring/reorientation process before the economic life-span of the plants has been completed, and before the costs of investments and organization have been recovered.

Of course, the essential foundations for this flexibility are the technologies and strategies selected, and internal professional skills.

c) Production scale.

Even the choice of ideal plant size is an essential step towards determining the traits of the business; it may proceed simultaneously with the two previous steps and is inevitably influenced not only by internal needs, but also the market type. This statement does not mean that a company must passively accept the existing situation of the domestic or international market, since it is always possible to change a pre-existing situation, as many cases have demonstrated. However, experience in recent years shows without a doubt that many errors have been made in choosing scale, to the point that in various branches of activity companies carry to much capacity, which translates into internal diseconomies.

A feasibility study should be carried out only if the necessary financing facilities, as determined by the studies, can be identified with a fair degree of accuracy. There would be little sense in a feasibility study without the reliable assurance that, in the event of positive study findings, funds could be made available. For that reason, possible project financing must be considered as early as the feasibility study stage, because financing conditions have a direct effect on total costs and thus on the financial feasibility of the project.

The economic and financial evaluation of the project at the company level can be done by means of the "cost-engineering analysis", the major aspects of which are discussed below.

In order to gather data capable of providing information on the validity of a project at the overall level (at least national), special attention must be given to shadow prices, which make it possible to establish the social value of the investment.

The social value — or shadow price — of the investment is the present net value of the aggregate consumption stream resulting "directly" and "indirectly" from a unit of the marginal investment.

The "shadow price" is also considered an appropriate measurement of the value of resources that a project provides from an alternative investment, or of the income generated by the project that are reinvested in something else.

If the benefits are not reinvested, only direct benefits are considered, and the shadow price of the investment depends solely on the productivity of the capital and the rate of social discount at which productivity is converted into current equivalents.

If the benefits are reinvested, the shadow price of the investment must also reflect the consumption produced indirectly from reinvesting a share of the immediate product of the investment; this represents the marginal tendency to preserve income as an additional factor in determining the shadow price of the investment.

The shadow price of the investment may vary over time, as it depends on current and future rates of productivity and capital maintenance.

If the data allow a sectorial division of the investment, it may be useful to distinguish the shadow prices of public investment from those of private investment.

The social value of the investment may be obtained by applying the following formula:

$$V_s^{inv} = \frac{(1-s)\ q}{i-sq}$$

where:

- $1-s$ is the share of consumption in the marginal return from investment;
- q is the marginal rate of return;
- i is the social discount rate;
- sq is the rate at which capital accumulates.

Given three cases, we can assess the social value of each investment.

	1st case	*2nd case*	*3rd case*
s	0.20	0.30	0.30
q	0.20	0.20	0.20
i	0.08	0.08	0.10

In the first case, the social value of the investment is:

$$\frac{(1.0-0.2)\times 0.2}{0.08-0.2\times 0.2} = 4$$

in the second case it is:

$$\frac{(1.0-0.3)\times 0.2}{0.08-0.2\times 0.3} = 7$$

in the third case it is:

$$\frac{(1.0-0.3)\times 0.2}{0.10-0.2\times 0.3} = 3.5$$

It is clear that the highest social value of the investment is achieved in the second case.

8.2. COST-ENGINEERING ANALYSIS

The economic and financial assessment of a project, and thus of the technologies adopted, is commonly done by means of a cost-engineering analysis, widely used throughout the world, and well described in all operative details (Park and Jackson, 1984; Collier and Ledbetter, 1982; Ahuja and Walsh, 1983; Blank and Tarquin, 1983).

Here it may be useful to consider the crucial and most arbitrary aspects that may be encountered in these assessments, so that they may be taken into account when making the consequent choices, especially when comparing projects and technologies with different characteristics.

As is well known, after defining the economic objectives, the cost-engineering analysis is divided into the following stages:

– definition of depreciation criteria;

– cost estimate;
– income estimate;
– estimate of the return on investment.

Difficulties may be encountered and errors made at each step; these must be known and quantified.

When defining depreciation criteria, if following the linear method, the shares are equal for each year of the economic life of the project, but no account is taken of the "increasing disuse" of plants, thus their obsolescence. In addition, the market conditions are not considered, which could recommend a criterion of increasing or decreasing amortization shares, depending on whether the market is saturated or penetrable.

When estimating production costs, the greatest difficulties are encountered in terms of raw materials and the energy used in production processes, since there has been high instability in these markets for years. Therefore, these estimates must take price fluctuations into account, and the company realising the project must operate in such a way as to diminish or eliminate these fluctuations as much as possible.

Estimating labour, running and maintenance costs is instead based on values referring to the depreciation shares, and thus are much more reliable, though still subject to a certain margin of arbitrariness.

One delicate and arbitrary point is the income estimate, both in terms of obtainable unit prices and saleable quantities.

These estimates must therefore be based on a detailed operative plan of how and where the products will be sold, defining the sales channels after analyzing the demand on the destination markets.

In order to become aware of risks and errors, one essential point is that of calculating the probabilities associated with risks, using consolidated statistical methods (Himmelblau, 1978) and error estimates, making adjustments to the original estimate, obviously using equally objective and realistic criteria.

Therefore, with the probability values associated with the risks and the estimate error, it is possible to have an analytical and precise knowledge of the reliability of the values.

It goes without saying that where results are not particularly reliable, new projects must be developed, changing the aspects and variables that lead to high unreliability, until more reliable results are obtained.

The methods for estimating the return of an investment (payout time, rate of return, net present worth, discounted cash flow), using monetary values (net profits and net cash flow) referred to different years, have the main

problem of their present worth being calculated, that is the choosing of the criteria and discount rate, which must be done in a reasoned way, also by using different hypotheses.

The tendency to prudently choose high discount rates, attributing greater importance to the initial returns and cash flows, tends to privilege investments in conventional technologies to the detriment of those that concern flexible technologies. The latter do indeed require higher initial investments, but tend to be more profitable in the long term.

The choice of discount rates and the criteria for accepting the investment must also take into account the type of project (development of new products, replacing equipment, etc.) and the strategies of the company.

When estimating the productivity of the investment, the estimate of the incremental income rate is important, especially useful when assessing projects having a different scale, or in the case of additional investments that improve productivity and efficiency, or those made necessary by environmental and safety needs.

If the results of the estimates are considered positive and recommend for realizing the project, while implementing and managing the project the company must scrupulously adhere to the criteria set during the preliminary estimate, unless the reference parameters and general conditions change during the economic life of the project itself.

Then the criteria and parameters must be changed to adapt to the new conditions, in order to achieve equally positive economic results.

8.3. ESTIMATING THE ECONOMIC INCOMPATIBILITY AND COMPLEMENTARITY AMONG BRANCHES OF ACTIVITY

Since the most significant drawbacks for the type and level of economic development appear to be the discontinuities that gradually arise either within the same industrial sector or even between the agricultural and industrial sectors (discontinuities mainly economic, organizational and occupational), it appears to be essential to establish — first generally and then with specific references — the incompatibilities between sectors which serve to avoid these inconveniences, and the complementarity relationships that serve instead to cause and determine a balanced growth of the economy.

In the meantime, we must establish the basis on which we can identify incompatibility and complementary relationships, taking into account the set

goals; for both, the aspects to assess include the existing structures, the infrastructures, the raw materials used, the technological level, the production cycle and added value, the level of investments, pollution, labour requirements, availability of labour in the area, the need for covered and uncovered areas, the homogeneity of the plants, the make-up of the territory and the external economies of scale that may be obtained from the induced activities.

A concrete example may be useful for this purpose.

Twenty-eight branches of activity have been considered, listed below, and each has been assessed in reference to the most significant parameters by adopting the following criteria:

Technology: traditional, intermediate, mixed, advanced.
Investments per employee: low, medium, mixed, high.
Labour requirement: low, medium, high.
Area requirement: low, medium, high.
Energy requirement: low, significant, high.
Pollution: none, low, medium, high.
Raw materials: not widely available, available, abundant.
Added value: low, medium, high.
External economies of scale: non-existent, low, medium, high.

It is implied that subsequent, quantified examinations can provide more detailed, operative and perhaps different results, but these are possible only in relation to specific situations.

The 28 branches of activity are:

1) Electrical materials
2) Iron metallurgical industries
3) Machine industries
4) Commercial activities
5) Service activities
6) Packing and containers
7) Furnishings
8) Textile industry
9) Fashion
10) Footwear
11) Organic chemical industry
12) Petroleum industry
13) Petrochemical industry
14) Coal conversion industry
15) Non-ferrous metals industry
16) Electroplating
17) Electrochemical industry
18) Electronics
19) Building materials
20) Ceramics
21) Construction
22) Precision industry

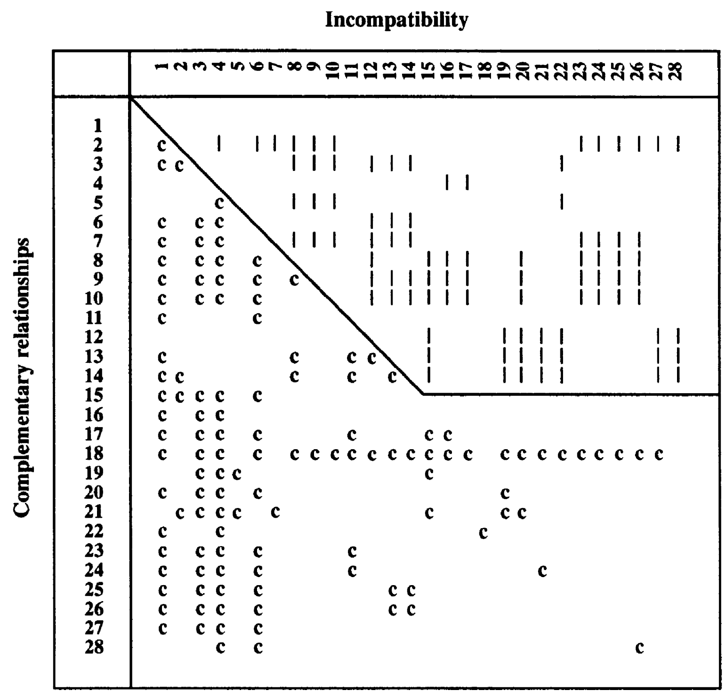

Figure 8.1. Diagram of incompatibility and complementarity relationships among branches

23) Paper and paper technology
24) Glass
25) Plastics
26) Rubber
27) Foodstuffs
28) Sale of agricultural products

The summary of these parameters leads to an evaluation of the economic incompatibility, neutrality and complementary relationships between branches of activity, which appear to be essential elements in making planned choices (see Table 8.1).

The matrix is shown in Figure 8.1.

The method indicated makes it possible to establish, indicatively, the main incompatibilities and complementarity relationships; as it is a method that uses classes and not point values, this does not make it possible to analytically assess and examine the degree of incompatibility or complementarity relationships. However, for the purposes of a plan that tends to bridge the gap between company needs and community needs, the method does provide sufficient concrete information.

TABLE 8.1. Assessment of 28 branches, considering the main parameters

Sectors	Technology	Investment per employee	Labour requirement	Area requirement	Energy	Pollution	Raw materials	Added value	External economies of scale
1)	intermediate	medium	high	medium	consid.	none	available	high	medium
2)	intermediate	high	medium	high	high	none	abundant	high	non-exist.
3)	intermediate	medium	high	high	consid.	low	abundant	medium	medium
4)		medium	medium	medium	low	none		high	low
5)		medium	medium	low	low	none		high	low
6)	traditional	mixed	high	medium	low	low	abundant	medium	medium
7)	traditional	medium	medium	medium	low	none	available	high	low
8)	traditional	medium	low	high	consid.	none	available	high	low
9)	traditional	low	high	medium	low	none	available	medium	low
10)	traditional	low	high	low	low	none	available	high	low
11)	intermediate	mixed	low	high	consid.	high	abundant	low	low
12)	mixed	high	low	high	low	high	scarce	medium	non-exist.
13)	mixed	high	medium	high	high	high	available	high	low
14)	mixed	high	medium	high	high	high	available	high	low
15)	intermediate	high	medium	high	high	medium	available	high	medium
16)	traditional	medium	medium	low	high	medium	available	medium	low
17)	mixed	medium	low	medium	high	high	abundant	high	medium
18)	advanced	low	high	medium	consid.	none	abundant	high	medium
19)	traditional	high	medium	high	consid.	high	abundant	high	low
20)	traditional	medium	high	medium	consid.	high	available	high	high
21)	traditional	medium	medium	medium	low	none	abundant	medium	high
22)	advanced	low	high	low	low	none	abundant	high	high
23)	traditional	high	medium	medium-high	low	medium	available	medium	medium
24)	traditional	medium	high	medium	consid.	low	abundant	medium	low
25)	advanced	medium	medium	low	low	low	available	medium	low
26)	mixed	high	medium	medium	consid.	low	available	medium	low
27)	mixed	mixed	high	medium	consid.	low	available	medium-high	high
28)		medium	high	medium	low	none	available	medium	medium

8.4. ASSESSING THE COMPATIBILITY BETWEEN ENVIRONMENT AND PRODUCTION TECHNOLOGIES

Each technology used by man to satisfy his production needs has direct and indirect effects on the environment, defined as the system within which various factors interact (air, water, soil, plant and animal world, climate, landscape, cultural heritage, man).

These disturbing effects risk becoming increasingly aggravated, to the point of irreversibly jeopardizing environmental balances, with the progressive spread of inadequate types and quantitative levels of production in industrialized and developing countries.

By now it is generally acknowledged that the environment is a good in its entirety, as is the system within which the conditions of man's life are set. Consequently, the awareness is growing of the absolute need to protect this good through the appropriate preventive as well as corrective measures.

In particular, we must know what real and/or potential disturbances derive from normal production activity, so that these may be designed and handled so as to avoid any negative effects on the environment.

For this purpose, environmental impact assessment (EIA) procedures have become common in recent years, consisting of developing a study that illustrates in detail the manufacturing activity or work subject to analysis, estimating the quality and quantity of disturbing factors, either how they appear from an industrial project to be carried out or resulting from real measurements of an already functioning activity (Leopold, Clarke et al., 1971; Baker, 1971; Pearce, 1979; Schmidt di Friedberg et al., 1984; Bresso et al., 1985; Clark, 1990; Polelli, 1989; Pearce and Turner, 1990). The values thus estimated and measured are compared to the features of the various "bodies" upon which there is a potential impact, with the purpose of establishing the entity of such impact.

Finally, the most appropriate means for mitigating this impact are indicated, and possible alternative solutions proposed.

Gathering the opinions of all competent authorities on these studies, and consulting the potentially involved public, we can arrive at a judgement as to whether or not the environmental cost of the project is acceptable. Obviously, the final decision is reached after examining a whole series of considerations, not just strictly environmental, but also economic, political and strategic.

Generally, the procedure tends to be divided into the following stages:

a) description of the activity to be analyzed and identification of the factors that may potentially cause impact;
b) description of the environment and assessment of the resources present in the area where the activity in question is to take place;
c) identification of impact (distinguishing between inevitable and/or irreversible);
d) identification of the cause/condition-condition/condition-condition/effect relationships;
e) reflection, aggregation and prioritizing of the types of impact.

In practice, these stages cannot be clearly distinguished from one another, but are part of a repetitive process in which each assumes the development of the others. Research on methodology is in constant evolution, and as of yet no standard methodology is available that is explicit and structured in each of its parts. The literature considers various methods, which would be better defined as support instruments for the procedure. Among the most frequently used instruments are:

– Checklists: this is the simplest system from a conceptual standpoint. They may range from simple lists of environmental factors to more complex tools, which require information to be gathered to foresee and quantify the impact of the activity on the environmental factors.

– Interrelation matrices: these are used to represent the cause-effect relationships between a certain intervention and a consequent environmental impact. These are dual-entry tables, listing the activities (or factors) that may have effects on the environment on one axis, and on the other the environmental characteristics (or components) that may be altered by the actions themselves. Each intersection between action and characteristic highlights and considers a possible impact. More sophisticated matrices and/or graphs make it possible to identify the secondary impacts consequent to a set of previously identified primary impacts (networks).

– Overlay mapping: this method is based on the integrated reading — often using a computer — of physical, ecological, social, and economic maps relating to a certain geographical area, for the purpose of obtaining information on the area's capability of accepting the manufacturing activity being studied.

– Mathematical models: there are various examples of models that simulate the environmental effects of a production activity. The complexity of these models, however, makes them generally unsuited to easy and effective practical use.

The instruments described above are not necessarily alternatives to one another, but may also be used together: for example, the information deriving from the use of check-lists may be used as a matrix input. The choice of instruments is closely related to the quantity and quality of information available and to the type of project to be analyzed.

The hierarchy created does not identify limits of acceptability or safety thresholds, but rather degrees of prevalence of certain causal factors with respect to others, of some potential environmental alterations with respect to others, and of some human activities influenced by the effects of environmental changes with respect to others.

This mainly serves to identify the best possible solution among the hypotheses, to make the corrective improvements necessary in order to reduce and/or compensate the effects of the impact, and to change the hierarchy of human activities influenced and disturbed by the effects of environmental change (Dixon et al., 1996).

A critical examination of the methods and applications of EIA first of all points out that the impact assessment is in any case quite arbitrary, since the "bodies" that receive the disturbance factors — with negative consequences — are not "fixed" but rather "mobile", in the sense that they are not entities in themselves but interact with each of the others, so as to vary the qualitative and quantitative connotations — over time and space — of the elements that combine to determine the "quality of the environment", including the ecosystem.

In second place, even if the impact assessment were reliable, it could be understood as an "authorization to disturb" once the type and entity of the disturbance are known.

If a manufacturing activity is the source of disturbances or has high risks, it must be placed in a condition to operate while respecting "environmental standards", which may be defined as the "maximum or minimum levels of the properties that make up the quality of the various bodies in the environment, which are acceptable in order to prevent environmental balances from being upset."

For the purpose of quantifying the impact within an EIA, it may be especially helpful to make use of environmental indices, an instrument that attempts to objectively and briefly express the qualities of environmental components (or resources).

These environmental indices are generally the result of functional calculations and aggregations of the physical, chemical and biological parameters that contribute to environmental quality, and one of their characteristics is that they are capable of varying continuously within a given value interval. This property makes them particularly suitable for expressing objectively the level of quality (or of pollution) of a particular location, and for evaluating even minimal differences in this level.

In addition to being an instrument for assessing environmental impact, the indices may be useful for systematically informing the public as to the quality of the environment, for controlling the respect of pollution regulation standards, and for quantifying the economic costs and benefits of environmental control strategies.

From the methodological point of view, the indices that can be found in the literature are, in most cases, determined by a procedure which can be summarized by the following phases:

(a) determination and selection of the parameters (variables) which contribute to environmental quality;
(b) identification of a variability interval for the parameters;
(c) introduction of weighting factors for each of the parameters considered;
(d) selection of the normalization functions (linear or non-linear) for the transformation of the values of the selected parameters in comparable sub-indices with uniform variability intervals; and
(e) adoption of an aggregation function which permits the realization of a final synthetic index starting from the sub-indices of point (d).

The phases relative to points (a), (b), (c) and (d) have been treated in different ways in many studies, with recourse being made to subjective evaluations, to the consultation of the specialized literature or experts (through the Delphi technique, for example), to the use of normative standards, or to the use of statistical techniques.

As far as the adoption of an aggregation function is concerned, it is possible to identify a number of principal groups of functions in the literature:

linear sum functions, arithmetic means, geometric means, maximum (minimum) operator functions (Smith, 1989; House, 1989; Steinhart et al., 1982; Bhargava, 1983; Inhaber, 1974a and 1974b).

The construction and the use of environmental indices has sparked off a widespread debate in the scientific world between supporters and opponents (Ott, 1978). On one side, some specialists (especially chemists, biologists and, in any case, those who are directly involved in the testing and analysis of the individual parameters of environmental resource quality) maintain that the use of environmental indices represents an excessive simplification of the extremely complex and diversified reality of the environment, and that in order to carry out an accurate analysis of the resources, it is essential to consider and analyse the values assumed by the individual variables which influence quality. On the other side, supporters of environmental indices appreciate the simplicity and the succinctness of this instrument which permits the making of rapid comparisons or analyses of temporal trends without the complication of having simultaneously to consider the numerous variables involved.

These divergences in basic requirements — all of which are equally valid — have led us to propose the construction of air and water quality indices (Barbiroli et al., 1992) through the use of a methodology which has already been defined and used for the calculation of a global performance index for durable goods (automobiles, aeroplanes, agricultural machinery, automobile air conditioners) (Barbiroli, 1989b) and for materials (Barbiroli and Fiorini, 1992).

This methodology entails obtaining a final synthetic index through the construction of intermediate indices of various levels. Each index of a particular level is obtained by the aggregation of two or more indices of a lower level. A hierarchical "tree" structure is thus used, running from bottom to top. In Figures 8.2 and 8.3 this structure is represented separately for each resource through the indication of the denominations of the indices belonging to different levels. The possibility of having indices characterized by different degrees of aggregation — up to now never considered in the literature — allows those that are using it to choose for each individual occasion the indices that are most suitable for particular requirements.

Even though EIA systems have been applied for years in various countries, some limitations are still present and further developments are needed to address the complex and global environmental problems.

Researchers have been studying and proposing methodological and procedural improvements which could greatly modify the role of EIA: cumulative

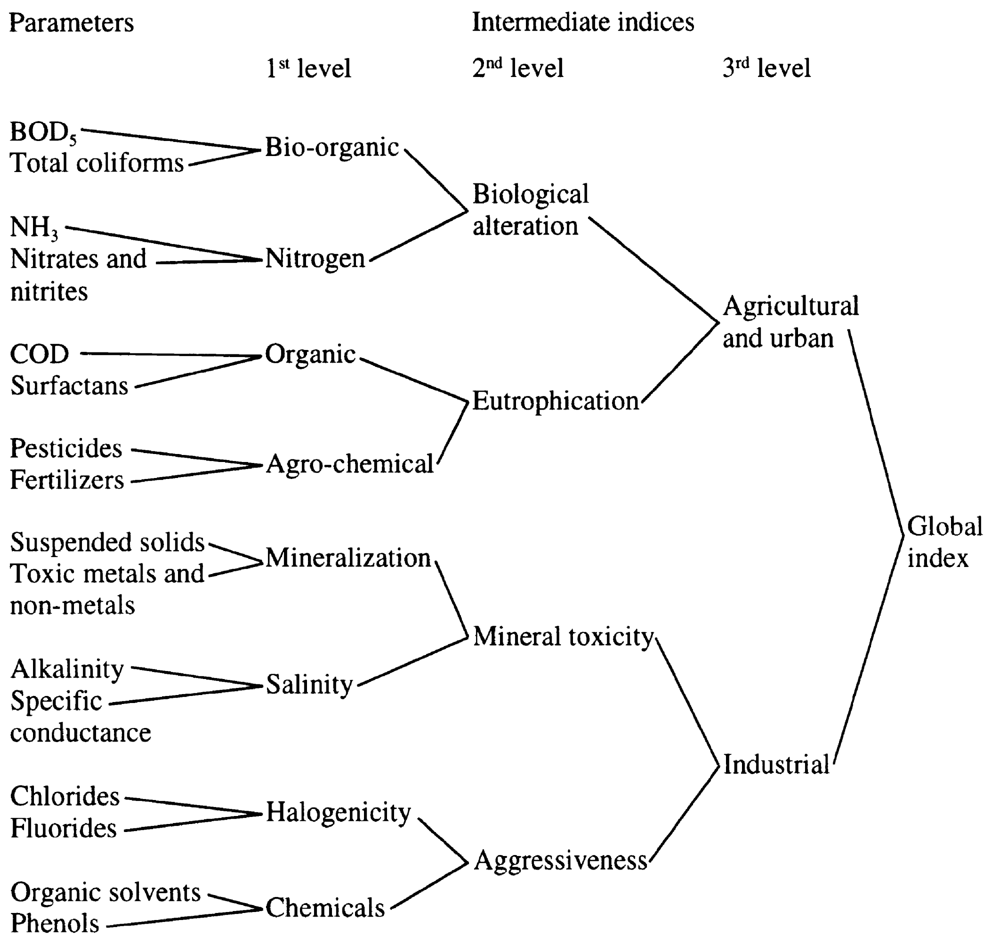

Figure 8.2. Tree-structured water quality index

impact assessment, strategic environmental impact assessment, development of specific methodologies, guidelines for specific situations.

Minor environmental burdens may generate a synergetic effect when they are concentrated in space and/or time. Whilst these cumulative effects of human activities have been seldom included in traditional assessment procedures, newly developed Cumulative Impact Assessment (CIA) are specifically addressing them, even though a number of methodological problems — mainly related to the complexity of ecological systems — have still to be solved.

Over the years it has become clear that environmental assessment procedures should be carried out not only at the project approval step and that great benefit would be obtained by reducing adverse impacts before proposals come through to the authorization phase, that is in the planning stage. Strategic EIA (SEA), indeed, refers to the assessment of environmental implications of higher tier actions such as policies, plans, and programmes.

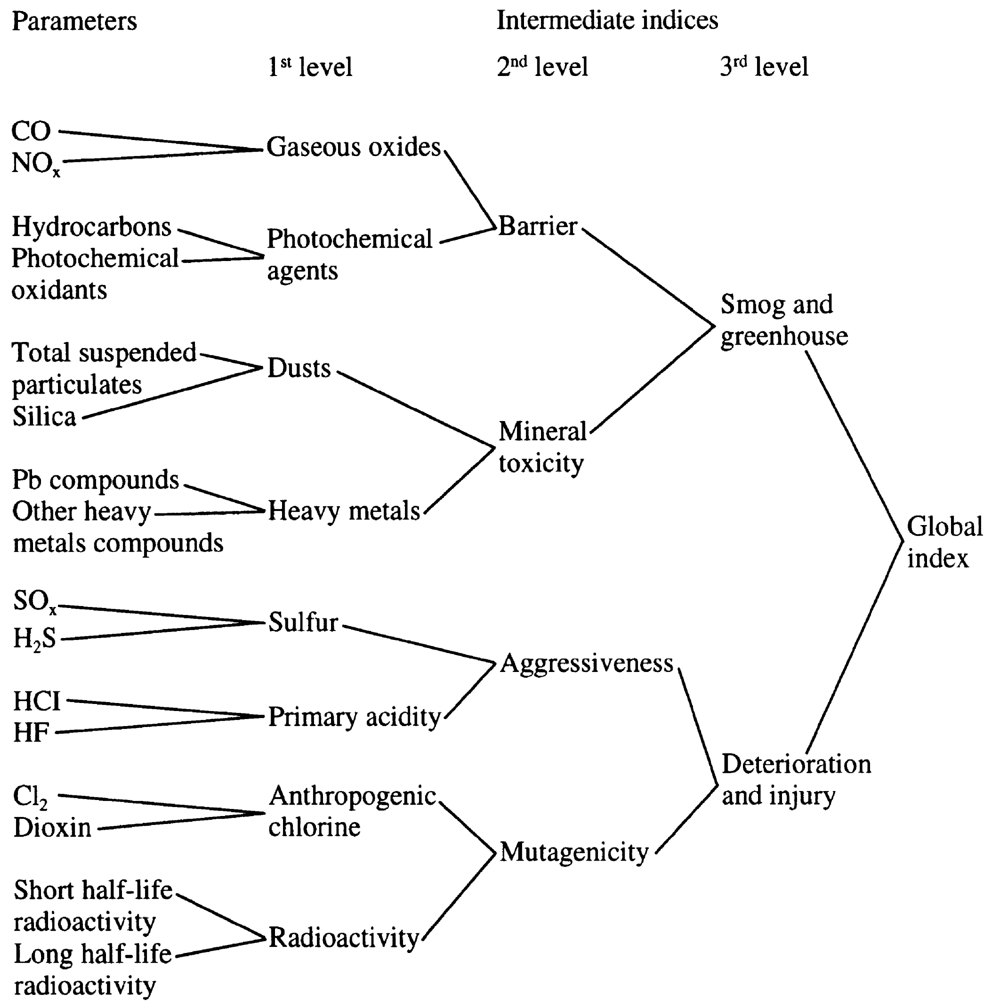

Figure 8.3. Tree-structured air quality index

Even though it is not a totally new notion, a renewed interest has recently risen on this issue. While EIA at project level is most detailed and quantitative, SEA can often only provide general information and is qualitative and indicative. These documents, therefore, supplement each other.

Further, specific environmental assessment methodologies and guidelines should be developed (e.g.: EIA systems for rural, urban and particular geographic areas). For instance, as far as developing countries are concerned, the main obstacles in applying EIA to project planning are the delay in project implementation, the lack of impact assessment experts and the additional costs mainly due to the lack of baseline data, which have to be collected.

Faced with the constraint of time, expertise and cost, developing countries should at least incorporate rapid assessment techniques (e.g.: checklists, matrices) in conjunction with a set of established guidelines.

8.5. ASSESSING THE LIFE-CYCLE OF PRODUCTS AND PROCESSES

Life-Cycle Assessment (LCA) is a recently developed method aiming at identifying and quantifying, on a life-cycle basis, the environmental consequences associated with products and/or processes.

Such an approach is not, indeed, a totally new one. First applied to environmental and energy issues in the 1970s, especially to measure the cumulative energy requirements for various industrial processes — a need driven by the energy crisis — it has received increasing attention in recent years as a possible environmental management tool.

Many environmental programmes of the past have succeeded only in transferring pollution from one medium to another — from water to air, or from air to solid waste. For example, when air pollution control equipment is installed in hazardous waste incinerators, large quantities of polluted wastewater may be generated by scrubbers. As a consequence, regulatory agencies have been recommending that companies adopt more holistic approaches to solving environmental problems. Moreover, there have been efforts in several countries to implement environmental labelling programmes, with a resulting interest in methods for acquiring and analyzing data to support these programmes. Finally, companies have been increasingly realizing the strategic role of environmentally-conscious production and adequate tools are needed to document claims of their products' environmental friendliness.

All of these issues have led to further develop and refine a standard LCA methodology, as a technical, data-based and holistic approach to define and subsequently reduce the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and material usage and waste discharges, assessing the impact of those wastes on the environment, and evaluating and implementing opportunities to effect environmental improvements (Curran and Vigon, 1993).

LCA is composed of various stages: goal definition and scoping, inventory analysis, impact assessment and improvement assessment.

In the first step, the objectives for carrying out an LCA are identified and the product/process system is clearly defined; the inventory step accounts for both the resource inputs and environmental outputs associated with the product/process; the impact analysis tries to determine the environmental impact of the inputs and outputs considered in the inventory assessment; finally, the improvement analysis identifies the strategic options for reducing the impact of the product/process on the environment.

The decision to perform an LCA is usually based on one of the following possible objectives:

- comparisons among alternative products and/or processes;
- identification of the points of the system where improvements may be achieved, from an environmental standpoint;
- constitution of an extensive set of information on a system's environmental loads;
- planning (determine whether decisions to modify a product/process will turn into a reduction in resource use or emission);
- guiding the development of new designs;
- public policy making: as a basis for eco-labelling or for banning or restricting any products.

A clear objective definition is essential for ensuring valid interpretation of the results. One of the initial key decisions is the suitable basis for comparison, which is usually referred to as functional unit. Comparisons, indeed, have to be carried out among products/processes delivering the same amount of functions or services. Also, clearly set boundaries directly affect the outcome of the study. It is fundamental, therefore, to determine exactly which steps of the production process have to be included in the life cycle and which variables are to be considered for each step (system length and breadth).

After having determined the system boundaries, it is possible to quantify the flows of energy and materials from and into the environment in order to produce a comprehensive inventory of system inputs and outputs. Even though the procedure for carrying out the inventory step may be considered well developed and accepted, a number of issues have still to be addressed, such as the availability of updated and accurate data, the allocation of environmental burden between co-products and in case of recycling (Hunt et al., 1992).

Once an inventory of materials and energy inputs and outputs is assembled, the impact assessment step is needed. Indeed, what is important is not a mere list of environmental inputs and outputs, but the problems caused by such inputs and outputs.

The information gathered, therefore, need to be simplified by aggregating the data (for instance, constructing synthetic indices). Even though the aggregation process involves subjective elements (weights) and entails a loss of information, it is necessary in order to make decision-making easier.

The development of feasible approaches to life-cycle impact assessment has been one of the major barriers to the implementation of LCA. Funda-

mental theoretical frameworks for impact assessment developed so far have proved difficult to put into practice given the data that are available from inventory studies and the constraints imposed by limited funding.

Studies have recently been carried out in order to develop a method to quantify the contribution of environmental inputs and outputs to a number of generally recognized environmental problems. This problem-oriented approach, developed by CML (Guinée et al., 1993), consists of some main steps: classification and characterization; normalization; and valuation.

In the classification step, generally recognized environmental problem types are identified. Then, all burdens are sorted according to the environmental problem they contribute to. For example, burdens that contribute to the greenhouse effect may be grouped together, as are impacts that contribute to ozone layer depletion. Certain impacts are included in more than one class. For example, NO_x emissions are toxic, acidifying and cause eutrophication. The characterization step consists of: the definition of classification factors indicating the contribution of one unit of environmental input or output to a particular environmental problem; the multiplication of environmental inputs and outputs with their classification factors and subsequent aggregation of the results for each problem type into a number of effect scores.

In order to gain a better understanding of the relative size of an effect, a normalization step is required. In this step, the effects are divided by a "normal" effect. By doing this, it is possible to obtain the relative contribution from a given product's life-cycle to each already existing effect.

Finally, a valuation step is needed to aggregate the scores into a final environmental index, through a multicriterion analysis, and to assess the reliability and validity of the results.

In the final LCA step improvement, options are identified. For this, two complementary techniques can be applied: the dominance analysis and the marginal analysis.

In the dominance analysis the main origins of the environmental problems are traced back. Through the inventory step results, substances that are considered a major problem can be traced back to processes responsible for them.

For the improvement of products, knowledge of the dynamic behaviour of the environmental profile in terms of process modification can be even more important. The marginal analysis is a technique which addresses this question. Processes to improve can be selected using knowledge of the sensitivity of the result to small perturbations in the economic or environmental process data (Fava et al., 1993; Nierynck, 1993).

Even though LCA requires further development and refinement, it should be considered as a basic strategic management issue.

As the ability to balance performance, cost and environmental characteristics becomes more critical to business performance, only those companies skilled in assessing and improving the environmental profiles of their products and processes will be able to achieve strategic advantages. Recently, the application of LCA has shifted from an external focus to internal assessment for strategic purposes. It can provide, indeed, on the one hand, the impetus to look internally, and examine ways to reduce costs associated with product manufacturing; on the other hand, it can provide a stimulus for product assessment, allowing a company to make the necessary business decisions for maintaining its competitive advantage in a market.

However, it should not be viewed as a single tool to solve all environmental problems. Product LCA highlights risks and benefits deriving from a specific change in a product or process and help assess potential environmental damage in an overall environmental approach. As such, it provides an additional perspective and approach which can be combined with existing pollution controls and pollution prevention approaches.

A company that recognizes the full value of LCA as a strategic planning tool will be in a better position to improve its environmental performance and gain competitive advantage.

LCA information, however, must be completed by additional information, such as total cost assessment, quality assessment, marketing studies and legal considerations (UNEP, 1996).

A comprehensive economic analysis can be accomplished to support a techno-economic evaluation; the analysis is composed of Full Cost Accounting (FCA) and Total Cost Assessment (TCA).

Full cost accounting is a tool used to identify, quantify and allocate the direct and indirect environmental costs of ongoing operations. FCA helps identify and quantify the following four types of costs for a product, process or project: direct costs (e.g. capital, raw materials); hidden costs (e.g. monitoring, compliance reporting); contingent liability (e.g. remedial liabilities); and less tangible costs (e.g. public relations, goodwill). FCA may be performed with varying degrees of intensity. In its initial or 'screening' stage, FCA involves a preliminary assessement of environmental costs and other traditional costs associated with a current process. This screening step can rely on known and readily available environmental costs, such as direct and obvious hidden costs.

The comprehensive FCA is an expansion of the screening activity and will typically involve data gathering and the evaluation of the types of costs listed above. Total cost assessment is used to assess projects using environmental cost data, appropriate time horizons and standard financial indicators.

Total cost assessment is a comprehenive method for analyzing costs and benefits of a pollution prevention or design project. TCA includes: (1) Full cost accounting; a managerial accounting method that assigns both direct and indirect costs to specific products. (2) Estimates of both short and long-term direct, indirect or hidden liability, and less tangibile costs. (3) Costs projected over a long horizon, such as 10–15 years.

8.6. MEASURING THE DEVELOPMENT POTENTIAL OF TECHNOLOGIES

Every technology has a typical life cycle. In the innovation/introduction phase, costs in relation to productivity are very high. This involves an increase in the average unit costs of production (Rosegger, 1986). In the development stage, productivity levels increase more than costs, and consequently, average unit costs of production fall. During the phase of stagnation, there is a return to the initial situation, since further efforts at improvement lead to increases in productivity which are less than proportional to the increase in costs. In this way, the average unit costs of production tend to increase.

It should be noted that, although productivity is a parameter that is fundamental to every production technique, there is another parameter of equal importance: the property/performance of the goods produced. Nowadays, in fact, there is a greater and greater tendency to improve the qualitative aspects of goods in order to be competitive.

In some cases it is possible to simultaneously improve productivity and properties/performances, while in others it is possible to improve only one of the two aspects. Increasing productivity leads to a reduction in unit costs when the technology is in the development phase; the company thus aims at increasing competitiveness through the reduction of costs. Improvement in the properties/performances of one or all of the company's products has the aim of increasing consumer approval, and, in this way, of increasing turnover.

In markets characterized by high competitiveness, companies tend to increase both productivity and performance in order to remain competitive (Edosomwan, 1988; Scherkenback, 1990). To achieve this, companies must dedicate more and more resources to R&D and to investment to increase turnover and reduce production costs at the same time. Positive results are obtained only during the development phase of a technology.

In an period of rapid and continuous transformations, production techniques must be constantly modified, either partially or totally. To make the best choices in the innovation of the process and/or the product, it is necessary to acquire all the elements relative to each possibility.

One of these, perhaps the most important, is the evaluation of the development and diffusion potential of a technology. Following up several research projects carried out over the last two decades, two original indices have been elaborated in order to analyse and evaluate the life cycle of a technology.

Development potential can be measured through the variations in the two fundamental success factors of any technology: productivity of the process/system, and properties/performance of the products. Sometimes, by changing the type and the combination of the factors, productivity can be improved; at other times, properties/performances can be improved; at still others, both can be improved. It should be specified that with current technologies — which are characterized by flexibility — the logic of productivity as it had been understood for decades has been profoundly changed, and, in the case of Just-in-Time production, the objective has become to make the single unit the most efficient number. In other words, in flexible production, what has become more important is the number of products, as well, of course, as the performance, rather than productivity in absolute. And in fact company strategy is becoming more and more oriented towards increasing the number of products, and leaving productivity and performances unaltered, or improving them only slightly.

For these reasons, the proposed method takes into consideration variations in productivity and performance, but referred to the range of products that is obtained at time 1 and at time 2. The first phase consists of calculating the two indices:

– the Global Performance Index (PG)

– the Productivity Index (PD)

One can reasonably suppose that relations of the following kind hold:

$$PG = C'_T \cdot \frac{(Production\ Costs)}{Turnover}$$

$$PD = C''_T \cdot \frac{(Investment)}{Turnover}$$

where the technological coefficients C'_T and C''_T take into consideration the capacity to transform a financial potential into a result. Naturally there are other factors which intervene, from management efficiency to "macro" variations, but for the purposes of this discussion we shall suppose that these other factors do not vary to a significant extent.

The idea is that the technological coefficients C'_T and C''_T can be significantly improved through adequate investments in applied research, by which is meant investments oriented towards the vertical development of a production technology.

Considering a period t_1, t_2 during which such investments have been made, the technological coefficients at the beginning and the end of the period must be obtained.

$$C'_T\ (t_1) = \left[PG \Big/ \left(\frac{Production\ \ Costs}{Turnover} \right) \right]_{t=t_1}$$

$$C'_T\ (t_2) = \left[PG \Big/ \left(\frac{Production\ \ Costs}{Turnover} \right) \right]_{t=t_2}$$

$$C''_T\ (t_1) = \left[PD \Big/ \left(\frac{Investment}{Turnover} \right) \right]_{t=t_1}$$

$$C''_T\,(t_2) = \left[PD \Big/ \left(\frac{Investment}{Turnover} \right) \right]_{t=t_2}$$

The Development Potential Index (DPI) is obtained by putting these variations into a relationship with the investments made. Thus given that:

$$\Delta C'_T = \left[C'_T(t_2) - C'_T(t_1) \right] / C'_T\,(t_1)$$

$$\Delta C''_T = \left[C''_T(t_2) - C''_T(t_1) \right] / C''_T\,(t_1)$$

DPI is defined as:

$$DPI = \frac{\Delta C'_T + \Delta C''_T}{\left(\frac{Research \quad and \quad Development \quad costs\ [t_1, t_2]}{Turnover\ [t_1, t_2]}\right)}$$

It is to be specified that the Δ of productivity and performance should be referred to the set of products as a whole that are obtained with each specific technology. Therefore, both the PG and PD indices must be a synthesis of the global variations of productivity and performance.

Consider a system that can produce the goods $b_1 \ldots b_n$; with each of these it is possible to associate a productivity (or performance) index: $p_1 \ldots p_n$

Let us now define an average index of productivity (or performance):

$$<p> = \sum_{j=1}^{n} \omega_j \; p_j \; ; \; \omega_j \in [0,1] \qquad = \text{quantity produced compared to total production}$$

Wherever one wishes to take into consideration this fragmenting of the production (understood as an advantage of flexibility) a composite index can be defined:

$$<p(\alpha)> = \left[\sum_{j=1}^{n} \omega_j^{\alpha} \; p_j^{\alpha}\right]^{1/\alpha} \quad ; \; 0 < \alpha \leq 1$$

which thus increases the value of the index as the number of products which can be produced increases. When $n = 1$, or $a = 1$, the two indices coincide. For a pre-established a, different from 1, the gain in flexibility is thus:

$$<g(\alpha)> = <p(\alpha)> - <p>$$

An example might make this easier to understand. Consider four different kinds of production, each with the same productivity index: $p_1 = p_2 = p_3 = p_4 = p_0$.

For the sake of simplicity suppose that $w_1 = w_2 = w_3 = w_4 = 1/4$, that is to say that the productions are equal.

One thus obtains:

$$<p> = p_0$$

$$<p(\alpha)> = p_0 \cdot \left[\sum_{j=1}^{n} \omega_j^{\alpha}\right]^{1/\alpha}$$

TABLE 8.2. Values used in seven real cases to elaborate the endogenous development potential index of a technology

		Global performance index	Productivity index	Production costs	Turnover	Investment	Research and development	$C'_T(t_1)$	$C'_T(t_2)$	$C''_T(t_1)$	$C''_T(t_2)$	Development potential index
	1984	20	120	5	9	27	0.4					
	1987	30	150	6	10	30	0.5					
Case 1	1990	40	180	8	12	36	0.1					
	1984-87				30		1.2	36	50	40	50	16.00
	1988-90				35		0.8	50	60	50	60	17.50
	1984	2	20	80	88	16	3.4					
	1987	2	30	90	100	20	3.2					
Case 2	1990	4	35	90	100	35	3.6					
	1984-87				280		10.0	2.2	2.2	110	150	10.36
	1988-90				300		10.4	2.2	4.4	150	100	19.04
	1984	7	40	80	95	8	2.0					
	1987	8	50	80	100	10	2.0					
Case 3	1990	10	70	100	130	13	2.0					
	1984-87				290		6.0	8.3	10	475	500	12.08
	1988-90				370		6.0	10	13	500	700	43.17
	1984	10	60	180	220	20	8					
	1987	18	75	190	250	35	10					
Case 4	1990	30	90	200	300	50	15					
	1984-87				720		27	12.2	23.7	660	535	20.00
	1988-90				880		40	23.7	45	535	540	19.98
	1984	60	20	60	70	20	3					
	1987	90	40	60	90	25	3					
Case 5	1990	120	80	60	120	30	5					
	1984-87				240		9	70	135	70	144	53.33
	1988-90				330		12	135	240	144	320	55.00
	1984	8	30	42	50	20	1.0					
	1987	10	36	43	50	20	1.0					
Case 6	1990	16	50	44	50	30	1.5					
	1984-87				150		3.0	9.52	11.58	75	90	21.50
	1988-90				150		3.5	11.68	18.18	90	83.3	23.33
	1984	6.5	22	37	44	15	1.0					
	1987	6.8	24	40	46	20	1.4					
Case 7	1990	7.0	24	42	48	24	1.7					
	1984-87				135		3.6	7.73	7.82	64.53	55.20	-11.18
	1988-90				143		4.8	7.82	8.00	55.20	48.00	-26.22

When $\alpha = 1/2$:

$$<p\ (1/2)> = p_0 \cdot 4$$

In reality, α should have a value very close to 1, $\alpha \cong 0.9$. Its value will however depend on the importance that is attributed to production flexibility (import $\uparrow$, value $\downarrow$).

As far as intrinsic development potential is concerned, an examination of Table 8.2 shows that cases 2 and 3 are, to different degrees of intensity, in a positive phase, while cases 1, 4, 5 and 6 are in a static phase, and case 7 is in a declining phase.

8.7. EVALUATING THE STRATEGIC VALUE OF TECHNOLOGIES

It is becoming more and more important from a political and economic point of view for a nation and its business enterprises to have at their disposal technologies that are both leading and fundamental — in the sense of being genuinely *original* — and that are capable of leaving a lasting mark on the development and improvement of economic activities and employment, on the environmental balance, and on scientific and social progress. It is not easy to establish whether, and in what measure, a technology is "leading and fundamental", and thus if it can be considered as "strategic". To establish this it seems essential to examine the conditioning factors within a particular system, given that the essence of being strategic, or "strategic value", has more sense and importance within a macro-system than within a single business enterprise.

Until now, this question has not been adequately tackled, even partially, but as in the case of some raw materials the idea of "strategic value" has been applied in a pre-established and stable manner to a few technologies used in industries that are considered to be "delicate", such as armaments, the nuclear industry, and the aerospace industry. However, with the onset of the new technical and industrial revolution, the selection and adoption of technologies that are capable of allowing an adopting enterprise to maintain its competitiveness, as well as to adequately satisfy the myriad requirements of a rapidly changing society, has assumed decisive importance, and should thus be considered as a phase which is crucial.

It goes without saying that unless the objective factors that permit one to establish whether and in what measure a technology is "leading" can be

identified, and so is therefore strategic, a subjective definition will not only have no conceptual validity, but it will also inevitably become counter-productive, because of the economic, political, and social implications that it will provoke.

It is necessary to specify that one must make reference to a "prevalent" technology, since any given technology is always composed of a set of "partial" technologies.

As a preliminary, to be able to arrive at a reliable and practical definition, one must consider numerous significant aspects that contribute to the identification of a "strategic" or "leading" technology, arriving at their definition, quantification, and correlation. Several hypotheses lead to a detailed proposal, based on 16 parameters which, though totally original — conceptually and formally — seem to have a validity and actual applicability (Barbiroli, 1990 and 1992).

a) A positive contribution (direct or indirect) to the trade and technology balances. Every technology requires basic materials and energy, which may be imported, and allows the production of goods, intermediate or finished, which may be exported, in the same way that plant machinery and know-how — in the various forms of technology transfer — can be imported or exported, this depending on the advantages that a specific technology offers to the business enterprise and the productive systems that adopt it.

A favourable balance of the money flow from the imported and exported goods and technologies for the country within which one wishes to evaluate the "strategic value" of a technology (produced by the same technology directly, and by correlated activities) in relationship to GNP represents the primary index of the capacity of a technology to have repercussions on an international scale.

To allow comparisons, prices must be corrected to the price index:

$$\frac{\Delta \text{ positive balance of trade and technology}}{\text{GNP, constant}}$$

It is expressed in percentages: the higher the percentage, the greater is the strategic value of the technology. In defining the degree of strategic value, negative values should not be taken into consideration. The actual field of variation is between 0.02% and 2%. Theoretically, higher or lower values are possible, but these cannot modify the basic configuration of the above-stated limits.

b) Share of international market. Each technology produces goods that inevitably mange to get onto the international market, acquiring market shares that determine their importance. This obviously depends on how competitive the goods are from the price, performance and marketability point of view. It can be expressed as a percentage of the total value of goods of the same category that are sold in one year on an international scale. The higher the share obtained by the products of the technology in question, the greater is its strategic value. Obviously, values can vary from 1% to 100%.

c) Direct economic importance. It is indispensable to know the dimensions of the direct economic relevance of a specific technology, in the sense of the annual global value of the products obtained using that technology. It can be expressed as a percentage ratio of the value of the products obtained with the technology in question and GNP. To allow comparisons, the values should be corrected to the price index:

$$\frac{\text{Annual value of specific products}}{\text{GNP, constant}}$$

The higher the values, the greater is the strategic value of the technology. The most probable field of variation is between 0.02% and 2%. Theoretically, higher or lower values are possible, but these cannot modify the basic configuration of the above-stated limits.

d) Induced economic importance. No technology is an end unto itself, in the sense that it is necessarily interdependent on other technologies and activities — which are reciprocally functional in any complex economic system. The global value of the goods which are in some way correlated to the technology in question — even capital goods — represents a measure of the relevance of induced economic importance. It can be determined as a percentage ratio of the annual value of the goods — intermediate and finished — obtained from the activities connected with the productive activity of the technology in question and GNP:

$$\frac{\text{Annual value of induced and correlated products}}{\text{GNP, constant}}$$

To allow comparisons, the values should be corrected to the price index: negative values are not to be considered in determining the degree of strategic value. The higher the values, the greater is the degree of strategic value.

The most probable field of variation is between 0.02% and 2%.

e) Number of alternative and equivalent technologies available. If, over and above the technology in question, there are no other technologies available to obtain similar products and perform similar functions within the same branch of industry, then that technology is unsubstitutable, and therefore has a higher degree of strategic value. If there are many alternative technologies, then it has a limited degree of strategic value. It can be expressed as an absolute number. Obviously, the higher the number, the lower is the strategic value of the technology.

The various situations that can actually be found range from 0 to 10. It is possible to find specific realities in which the number of alternative and equivalent technologies available is greater than 10, but this does not substantially change the possibilities of choice, which is high in any case, and is such as to make us consider the technology in question as having (at least as far as this measurement is concerned) a low degree of strategic value.

f) Interruptibility. As already mentioned, every technology is a part of an economic system with which it interacts to a considerable degree. The greater the constraints of interdependence, the less interruptible is the system of connections if the substitution of the technology whose importance and degree of strategic value one must establish is desired. Therefore, if this technology is rigidly functional to a system, it is to be considered unsubstitutable, and indispensable to the system. The level of "interruptibility" is fundamental in the evaluation of strategic value. It can be measured as a percentage variation of the overall value of the product, which is obtained either by substituting or eliminating the technology in question due to the losses or increases in productivity/efficiency of the whole system in relation to the initial value (i.e. before the introduction of the technology in question:

$$\frac{\begin{array}{c}\Delta \text{ value of the overall product substituting}\\ \text{or eliminating the technology in question}\end{array}}{\text{value of the overall product before substitution}}$$

To be considered strategic, a technology should not be interruptible, or it should have only a limited interruptibility. Realistically, values can vary from 100 (minimum interruptibility) to 1 (maximum interruptibility).

g) Specific development potential. Each technology has a different development potential, i.e. growth potential in productivity, properties/performances, and diversificability of the products. The greater this potential, the more "fertile" is the technology, the greater are its prospects for success — both directly (through the competitiveness of the adopting enterprise), and indirectly (through its being adopted by other enterprises in the same industries) — and the more it becomes strategic. If these conditions do not hold, the technology can be considered "sterile".

The method for evaluating development potential has already been proposed in Section 8.5.

h) Degree of pervasiveness (penetration and capacity for diffusion) in other productive branches. This aspect helps to determine the economic importance of a technology — and not just in a strictly business sense. If a technology can be transferred to other branches, it evidently has the capacity to contribute to the development of other activities, and to condition them.

The degree of pervasiveness can be expressed as a ratio of the investment made to adopt the technology in question (making the necessary adjustments) in all the other productive branches, and the investment made in the branch in which the technology originated over a three-year period.

i) Incidence of software, learning, and professional training costs. Each technology requires not just equipment, but also programmes, and learning and professional training costs which differ from one case to the next. The tendency towards the growing development of non-material aspects — a tendency that began with the new technological revolution — now means that these aspects become more important with the growth of improvements in the technology. There is no doubt, in fact, that know-how is the most strategic factor for obtaining the most favourable results. It can be measured as the incidence of the costs for software, learning, and professional training that must be met in a three-year period on the costs of investment in equipment over the same period:

$$\frac{\text{Software, learning and professional training costs (in three years)}}{\text{Initial investment}}$$

The higher the values, the greater the strategic value. The most probable variation range is 1–100%. Values over 100% are possible, but they cannot change the status of high relevance of software and know-how.

j) Impulse given to overall intellectual employment. In the same way that direct know-how is required for optimum functioning, an increase in intellectual employment caused either directly or indirectly by the adoption of a technology is also to be considered as desirable and positive. It can be measured as a variation in the number of posts for intellectual employment which a given technology requires, either directly or indirectly, compared to the number of posts for intellectual employment that exist within the country over a three-year period:

$$\frac{\begin{array}{c}\Delta \text{ posts of intellectual employment} \\ \text{necessary for the functioning of a technology}\end{array}}{\begin{array}{c}\text{Total number of posts in intellectual employment} \\ \text{over a three year period}\end{array}}$$

Negative variations are not to be considered. The higher the value, the greater is the strategic value of a technology. They may vary from 0.01% to 0.1%. Higher or lower values than those indicated do not substantially modify the characteristics of "low" or "high" levels of know-how.

k) Versatility. Each technology originates with particular characteristics, and among the most important of these is versatility, *i.e.* its capacity to supply different products with few adjustments in both the production organization and process. It can be expressed as the number of articles, even very different ones, that can be produced according to the principles of Just-In-Time. The higher the number, the greater is the degree of strategic value of a technology.

Possible values vary realistically from 1 to 100. Technologies capable of supplying a good deal more than 100 articles may exist, but at such levels the technology must already be considered as highly versatile, and allowing higher values would not substantially change the reality of the situation.

l) Flexibility. The natural component of versatility is the degree of flexibility of a productive system. The most desirable degree is that defined as "instantaneous". The way to measure the degree of flexibility has already been shown in Section 1.7.

m) Degree of exploitation (rational utilization) of raw materials used in the process. In a company which, as a result of the scarcity of certain resources, or of their excessive cost, tends to substitute them with "artificial"

and even complex products, the greater the added value obtained with one production process compared with the original value obtained by the raw materials, the greater is the validity of the technology.

The degree of exploitation can be measured by the ratio of the added product value and the final product value (as already shown in section 9.5).

n) Degree of exploitation of energy resources. As for the degree of exploitation of materials, the degree of exploitation relating to energy resources is equally, and perhaps even more, important in the evaluation of the "quality" of the technology, in the sense of its capacity to be a reference point of a more general tendency of the growing exploitation of energy resources and the decreasing incidence of energy costs on the value of the product.

This value can be measured as already shown in Section 9.5.

o) Direct environmental improvement. Given that the ecological balance has become a critical element in all productive activity, a technology which prevents or eliminates any form of disturbance of this balance is advantageous for society as a whole. All other things being equal, its adoption is facilitated and made more attractive. The degree of "environmental improvement" of a technology can be expressed as the ratio of the overall investment and running costs (both direct and indirect) incurred to maintain environmental balance and quality, and the value of the product obtained, over a three-year period:

$$\frac{\text{Investment and running costs to maintain environmental equilibrium}}{\text{Value of the products obtained in three years}}$$

The lower the value, the higher is the strategic value of the technology. The most probable values may vary between 1% and 100%.

p) Direct and induced contribution to the development of environmental technologies. If the technology whose strategic value is to be evaluated is characterized by a conceptual and innovative content, such as to form the basis for contributing to general improvements in the systems that are capable of raising the quality of the ecosystem and safety levels, this is to be considered as a positive element in terms of its strategic value. In fact these conditions can become opportunities for economic development in a broad and modern sense of the term.

It can be measured as a ratio of the value of the new general systems for the environment, the new materials, and the new know-how in all its forms which are obtained as a consequence of the environmental innovations of the technology in question and GNP, with values corrected to the price index:

$$\frac{\text{Value of new environmental technologies}}{\text{GNP, constant}}$$

Values may vary from 0.02% to 2%. It is possible to find cases with values higher or lower than those indicated, but the characteristics indicated by this field of variation are not substantially modified.

It is necessary to specify that the measurement of each of these 16 aspects of a technology is often neither easy nor exact, especially when official data are lacking or unreliable. If evaluations are made with reference to technologies that have been adopted for years, these limitations are less relevant. If the technology has been recently adopted, or if it still has to be adopted, then the uncertainties that follow on from the lack of data are considerable.

When the data relative to each of these 16 parameters have been calculated — even approximately — if a measure of the level of strategic value is required, it is possible to proceed to subsequent calculations which consist in the coupling of two parameters representing two manifestations of the same aspect to obtain intermediate synthetic indices (or sub-indices) at a first, a second, and a third level. The methodology is that indicated in Section 1.7. A scheme of the proposed procedure is given in Table 8.3.

The main problem of this method lies in fixing the weights that each parameter is to have. In fact, the 16 parameters have different levels of importance, both in general and in reference to specific situations.

Six different real cases have been taken into consideration; the values referring to the 16 parameters are reported in Table 8.4. The results of the first, second, and third level sub-indices and the final strategic value index may be found in Table 8.5. The firms that have provided the data are not mentioned for obvious reasons of confidentiality.

The different values obtained permit us to highlight the fact that the proposed method has an actual application to all cases where data are recoverable with sufficient approximation. One consideration may be drawn from the results obtained with equal or different weights for the 16 parameters; some data show that the differences between the first, second and third level sub-indices and the final index are small. This means that the weights are

TABLE 8.3. Prospect of the 'relevance tree' to elaborate a strategic value index

Parameters and methods of measure	Variation range	First level sub-indices	Second level sub-indices	Third level sub-indices	Strategic index
(A) Positive contribution (direct or indirect) to the trade and technology balance $\left(\frac{\Delta\text{ positive balance of trade and technology}}{\text{GNP.constant}}\right)$	0.02–2%	International economic importance	Global economic importance	Global economic vitality	Strategic value
(B) International market share of the products obtained	1–100%				
(C) Direct economic importance $\left(\frac{\text{annual value of specific products}}{\text{GNP.constant}}\right)$	0.02–2%	Domestic economic importance			
(D) Induced economic importance $\left(\frac{\text{annual value of induced and correlated products}}{\text{GNP.constant}}\right)$	0.02–2				
(E) Number of alternative and equivalent technologies available	0–10	Indispensability	Nodality		
(F) Interruptibility $\left(\frac{\Delta\text{ value of the overall product (substituting or eliminating the technology in question)}}{\text{value of the overall product before substitution}}\right)$	1–100%				
(G) Specific development potentiality $\left(\frac{\Delta\text{ productivity} + \Delta\text{ performances of the production}}{\Delta\text{ turnover, }\Delta\text{ investments, }\Delta\text{ production costs, and }\Delta\text{ R\&D costs over a 3 year period}}\right)$	0–50	Development capacity			
(H) Pervasiveness (diffusibility) in the productive system $\left(\frac{\text{investment in all branches over a 3 year period}}{\text{investment in the branch of origin over a 3 year period}}\right)$	1–10 000%				

TABLE 8.3. Prospect of the 'relevance tree' to elaborate a strategic value index (*continued*)

Parameters and methods of measure	Variation range	First level sub-indices	Second level sub-indices	Third level sub-indices	Strategic index
(I) Incidence of software, learning and training costs $\left(\frac{\text{software, learning and professional training costs}}{\text{initial investment}}\right)$	1–100%	Knowhow	System quality	Global value of the system	Strategic value
(L) Impulse given to intellectual employment $\left(\frac{\Delta\text{ posts in intellectual employment necessary for the functioning of a technology}}{\text{total number of posts in intellectual employment over a 3 year period}}\right)$	0.01–0.1%				
(M) Versatility (number of complete articles that can be produced Just-in-Time	1–100	Adaptability			
(N) Flexibility $\left(\frac{\text{total time required for all possible adjustments}}{\text{total time of production process for all possible articles}}\right)$	1–100%				
(O) Degree of exploitation of raw materials used in the process $\left(\frac{\text{added product value}}{\text{final product value}}\right)$	10–100%	Exploitation of resource	Qualification of natural resource		
(P) Degree of exploitation of energy resources $\left(\frac{\text{product value} - \text{energy value}}{\text{product value}}\right)$	1–100%				
(Q) Direct environmental improvement $\left(\frac{\text{investment and running costs to maintain environmental equilibrium}}{\text{value of the products obtained in 3 years}}\right)$	1–100%	Environmental improvement			
(R) Direct and induced contribution to the development of environmental technologies $\left(\frac{\text{value of new environmental technologies}}{\text{GNP.constant}}\right)$	0.02–2%				

TABLE 8.4. Values of the 16 parameters useful for measuring the strategic value, for the six cases referred to

Factors	Weights		Cases 1	2	3	4	5	6
A	1	3	0.03	0.27	1.30	0.70	1.1	1.7
B	1	2	10	17	6	8	15	25
C	1	1	0.10	0.20	0.80	0.60	1	1.5
D	1	2	0.30	0.60	1.40	0.90	1.2	1.4
E	1	3	3	5	1	1	2	3
F	1	3	20	10	10	5	30	50
G	1	2	5	10	15	25	30	50
H	1	2	100	200	1000	2000	4000	8000
I	1	3	20	25	30	35	60	80
L	1	1	0.08	0.18	0.25	0.25	0.1	0.07
M	1	1	10	80	30	100	60	100
N	1	2	10	10	30	30	50	70
O	1	2	40	50	30	40	70	85
P	1	2	80	85	70	75	90	90
Q	1	2	5	25	15	30	1	1
R	1	2	0.10	0.20	0.05	0.40	1	1.6

not decisive for the calculation or, at least, that different weights do not give final results that are correspondingly differentiated. Moreover, the attribution of different weights may be considered highly subjective. In conclusion, different weights leave the method open to criticism without giving meaningful differences. In any cases, to compare results when various technologies have to be considered, the choice between equal or weighted values must always be uniform.

* * *

By considering the aspects discussed above, it is now possible to identify and, consequently, adopte technological trajectories that are strategic and suitable to achieve specific economic and social goals, as, for istance, those considered and suggested in a recent research work with reference to a sustainable development (Barbiroli, 1996e).

However, these or other trajectories must be developed within a context of systematic technology policy, both at national and international level, in order to increase the positive effects of technologies and to reduce the negative ones (Barbiroli, 1996b; OECD, 1994; Becker and Kuhlman, 1994).

TABLE 8.5 Values of the global strategicity index (GSI) and the sub-indices, for the six cases considered, either with equal weight or with different weight between the 16 parameters

Values of sub-indices	1		2		3		4		5		6	
	Equal weight	Different weight	Equal weight	Different weight	Different weight	Different weight	Equal weight	Different weight	Equal weight	Different weight	Equal weight	Different weight
First level												
1	0.48	0.40	1.44	1.40	3.48	4.08	2.07	2.34	3.43	3.84	5.46	6.06
2	0.91	1.01	1.92	2.26	5.45	6.00	6.69	3.94	5.45	5.62	7.22	7.14
3	19.00	5.54	7.04	7.05	5.05	5.05	5.30	5.30	4.54	4.54	4.03	4.03
4	0.55	0.55	1.10	1.10	2.00	2.00	3.50	3.50	5.00	5.00	9.00	9.00
5	1.31	1.62	2.07	2.25	2.68	2.80	2.93	3.20	3.43	4.70	3.97	5.97
6	0.91	0.91	4.44	3.26	2.93	2.93	6.46	5.29	5.45	5.29	8.49	7.98
7	5.66	5.66	6.46	6.50	4.60	4.60	5.40	5.40	7.83	7.83	8.66	8.66
8	0.40	0.40	1.67	1.67	0.80	0.78	2.42	2.42	2.48	2.48	3.99	3.99
Second level												
1	0.69	0.65	1.68	1.72	4.47	4.79	2.88	2.94	4.44	4.51	6.34	6.46
2	9.80	3.54	4.07	4.67	3.52	3.83	4.40	4.58	4.77	4.72	6.51	6.02
3	1.11	1.31	3.26	2.68	2.80	2.86	4.70	4.08	4.44	4.95	6.23	6.84
4	3.03	3.03	4.06	4.06	2.69	2.69	3.91	3.91	5.16	5.16	6.33	6.33
Third level												
1	5.24	2.26	2.88	3.35	4.00	4.25	3.64	3.85	4.61	4.63	6.43	6.22
2	2.07	2.17	3.66	3.37	2.75	2.77	4.31	4.00	4.80	5.05	6.28	6.58
Global index	3.66	2.22	3.27	3.37	3.37	3.58	3.97	3.92	4.70	4.82	6.35	6.38

8.8 ANALYZING COMPETITIVENESS AMONG TECHNOLOGIES

A) Predation among technologies

In recent decades, the most characteristic aspect of industrial and economic development has been — and still is, with increasing intensity — the competition/interchangeability among different, alternative technologies, which make it possible to achieve either the same product by using different methods and operations, or different products and, obviously, different methods, which are however capable of satisfying the same needs. The increase in pure and applied knowledge, as well as the scientific transformation of technology, is accompanied by an ever-increasing number of alternative technologies capable of satisfying the needs of businesses on the one hand, and society as a whole on the other. And this should be considered a positive occurrence, as after evaluating the positive and negative aspects of each technology we can now choose the one most suitable for achieving the objectives for which it is to be used.

The analysis of competitiveness among different technologies available is, today, an increasingly significant stage of every decision-making process.

One of the main problems to be defined is the distinction between predatory actions and competitive actions (Scharfstein, 1984).

The distinction is essential, especially for the consequences generated by the behaviours of both the companies operating on the market, and of governments who decide on the economic policies to adopt in order to correct or orient each existing situation according to the objectives they wish to achieve.

For companies, it is essential to know the parameters, conditions and mechanisms governing market behaviours so that they may define their strategies, both for entering the market and for development. Even an innovation may be introduced in "predatory" or "competitive" form.

It should be specified that the market penetration policy of a business may be considered as predatory only if the prices are below the marginal cost (Areeda and Turner, 1975). This situation leads to specific consequences for all economic operators on a market.

For governments, this knowledge is just as essential in order to lay down the rules according to which companies must operate.

Indeed, if a predatory policy is adopted, a market is destabilized; vice-versa, a competitive policy creates dynamic conditions or equilibrium (Fundenberg and Tirole, 1986; Hart, 1983).

There are various ways to develop and use models capable of representing a predatory or competitive situation, and explain the reasons behind it. This is useful not only for analysis, but also for forecasting the prospects of each technology.

This section examines and discusses "predator-prey" models, and makes an innovative proposal with respect to those widely prepared and used in the field of economics (Ritelli, Barbiroli and Fabbri, 1997).

Some well-known biomathematical models describe the demographic pattern of an ecological system through autonomous differential equations. These equations represent the passage of time and interaction between the number of predators and the number of prey, in what is called the food chain or Lotka-Volterra predator-prey ecological model. This model dates back to the independent studies by Lotka (1925) and Volterra (1927).

If $x = x(t)$ denotes the number of prey, and $y = y(t)$ the number of predators, assuming that the growth rate for each species during an assigned time period is in proportion to the number of members of the species at that time, and allowing the growth rate of the prey to be Malthusian — i.e., specific and constant — we are thus led to the following system of differential equations:

$$x' = x(a - by),\ a,b > 0$$

$$y' = y(-\gamma + \delta x)\ ,\gamma,\delta > 0.$$

The system of differential equations written is known as the Lotka–Volterra predator–prey model, and is obviously the simplest of this type of model analysing this type of demographic interaction. Further and more recent works (Armstrong, 1976; Freedman, 1979; Rosenzweig and Mac Arthur, 1963) generalize the original model by introducing the concepts of functional response by the predators p and the evolutionary expansion rate of the prey g, thus achieving a set of differential equations as follows:

$$x' = xg(x) - yp(x)$$

$$y' = y[-s + c\ \ p(x)]$$

where *s, c* are two positive constants. Other works (Freedman and Waltman, 1977), increase the number of species struggling for survival, considering

systems in which species 1 is preyed upon by species 2, which in turn is preyed upon by a species 3, and so on, in what is known as a *food web*.

The problem of studying the behaviour of two species of predators who live off the same prey is dealt with in Koch (1974) and Rescigno (1977).

According to the type of model being examined, or even changes in the original conditions within the same model, various results are possible:

i) the number of prey tends towards zero for $t \to +\infty$, and thus the prey species becomes extinct;

ii) the number of predators tends towards zero for $t \to +\infty$, and thus predation is not possible;

iii) both the number of predators and that of the prey settle around a constant value; thus we have a situation in which the two species coexist; coexistence may have various characteristics of stability, that is, slight variations in interaction between the populations may either cause no variation in the demographic balances, or lead to the extinction of one or both species;

iv) limit cycle phenomenon (Cherkas and Zhilevich, 1970; Freedman and Kuang, 1988; Zhang Zhifen, 1986): a set of periodic oscillations occurs between the number of representatives of the species in play.

The purpose is to critically transpose the techniques used in biomathematics for use in examining the evolution of a market. There are two possible models, the first of which is inspired by the techniques explained in Freedman and So (1985), and which we shall call the model of *exogenous competition*, while for the second we shall adopt the techniques of Freedman (1979) in what we call the model of *endogenous competition*.

In the first, we shall suppose that at a certain moment t_0 there exists a situation of balance between the number $x(t_0)$ of potential consumers of a certain product, and the number $y(t_0)$ of products actually placed or, in the case of continuous goods, the function y will represent the quantities placed on markets in terms of the unit of measure specific to the product (tons, gallons, etc.). The objective is to examine the possibility for a new manufacturer, using alternative technologies, to penetrate the market; this manufacturer shall place a quantity of goods denoted as $z(t)$ on the market at the precise moment $t \geq t_0$ (Lefschetz, 1957; Loud, 1964).

The second model will instead attempt to study the stability of a market in which there is a competition situation among competitors using the same production technologies. Here again, $x(t)$ will represents the number of potential consumers of the product in question, while $y(t)$ will represents the quantities of this product absorbed by the market. We shall examine the sta-

bility of equilibrium configurations, where they exist, and check whether, according to a mathematical interpretation of our model, competition has a stabilizing effect on the market, at least in the short term.

We feel it best to reveal the main limitation related to the use of biomathematical models: sets of independent differential equations, thus not explicitly dependent upon the time variable, are certainly suited to a global description of biological phenomena, where the parties in play interact without the possibility of changing their strategy. This global time description is not possible through independent representation should one wish to analyse the dynamic evolution of an economic system. It is impossible to hypothesize that, in the presence of competitive situations, thus after the entrance of new contenders, the previous competitors fail to change their market strategies in order to ensure "survival" (Hethcote et al., 1981).

The formulation proposed, then, should be accepted with the awareness that we are studying an economic system from a standpoint limited in time, as the various parameters of which the model consists must be gradually changed in order to continue the study for longer periods (Ritelli, Barbiroli and Fabbri, 1997)

B) Competitiveness and coexistence among technologies

The problem of competitiveness or co-existence among different technologies able to achieve equivalent products, from both a techno-qualitative and economic viewpoint, thereby mutually replaceable in their specific uses, is usually dealt with in economics through the analysis of economic equilibrium. This leads us to use the theory of games, as clearly emerges in the literature (Basar, 1986; Kamien and Schwartz, 1981, 1983; Jørgensen, 1983, 1986; Mahajan and Muller, 1979; Mahajan and Peterson, 1979, 1982).

However, the increasing turbulence of markets (demand instability, resource availability instability) and of external factors (environmental, political, social) are such to strongly modify the global context in which the life-cycle of all producing activities takes place; consequently, the bahaviour of each technology is highly influenced by these factors.

In these circumstances, the models referring to conditions of equilibrium do not appear completely suitable to express and explane the new realities in which technological competition and its dynamics take place.

Our purpose was to create some models able to express these conditions of unbalance.

First and foremost, we have chosen to present aggregate models implying the presence of only two rival producers; such simplification avoids giving rise to excessive technicality in the mathematical analysis of the models.

As a matter of fact, dynamical systems that evolve in dimensions ≥ 4 still present many aspects that are not yet completely understood in theory.

In dimension two the information on the dynamics of the systems is quite complete; while, beginning with dimension three, several mathematical phenomena may arise that are not completely understood (Tu, 1992).

In the second place, we have chosen to work in a deterministic environment by interpreting the alterations of the market stability through the variation of production costs, which may be considered variable for both endogenous and exogenous reasons.

Actually, it is often not feasible to directly quantify the influence of exogenous factors.

For instance, we may think of the constraints related to environmental factors. The case of nuclear power stations is very significant in this area: it is possible to calculate precisely the production costs of a kWh in a nuclear station, including all the external factors (safety systems for reducing the accident probabilities, removal of radioactive wastes, decommissionng, etc.). As a consequence to these rising costs, all nuclear plants have modified the production costs of the kWh in such a way that development programs for nuclear plants have been dramatically slowed down all over the world. This new economic reality creates the premise to introduce new competitive energy systems and technologies.

In the proposed simplification we will try to reach the stated aim by expressing the unit production cost of the good x_i by multiplying it by a suitable coefficient g_{ij}, positive and less then 1, so that the amount $x_i \cdot g_{ij}$ represents the costs met caused by both the endogenous features of the process technologies and by marketing, advertising and other quantifiable exogenous factors (also calculated at the final stage of production).

Obviously, it is always possible to adequately reinterpret the variations of cost so pointed out as variations of return (opposite sign, of course), connected with phenomena of the demand curve variations in each enterprise.

At the level of the chosen abstraction in this work, a greater specificity in the formulations seems inopportune.

The models introduced in this section have been proposed by Barbiroli and Ritelli (1997) and should be able to study factors and rules determining

competitiveness or coesistence among technologies, under different market conditions.

Static market conditions. Let us suppose that two competing technologies place finished products on the market at moment t in quantities of $x_1(t)$, $x_2(t)$, respectively. The problem is to reasonably define the product obtained from each of the contenders, in relation to the technologies used to produce the consumer goods. These technologies are assumed to be antagonists. In a hypothesis in which all of the production is absorbed by the market, the profit per unit of good produced will be represented by the equations:

$$\begin{cases} p_1 = \dfrac{a}{x_1 + x_2} - (c_1 + g_{11}x_1 + g_{12}x_2) \\ p_2 = \dfrac{a}{x_1 + x_2} - (c_2 + g_{21}x_1 + g_{22}x_2) \end{cases}$$

with the symbols having the following meanings:

a monetary availability of all consumers as a group (supposed to be constant);

c_1, c_2 unit production costs sustained by manufacturers 1 and 2, respectively;

$g_{11}x_1$ additional costs sustained by manufacturer 1, caused by the presence on the market of other manufacturers of the same type, *intraspecific competition coefficient*;

$g_{12}x_2$ additional costs sustained by manufacturer 1, caused by the presence on the market of other manufacturers of the type 2, *extra specific competition coefficient*;

$g_{21}x_1$ additional costs sustained by manufacturer 2, caused by the presence on the market of other manufacturers of the type 1, *extra specific competition coefficient*;

$g_{22}x_2$ additional costs sustained by manufacturer 2, caused by the presence on the market of other manufacturers of the same type, *intraspecific competition coefficient*;

where we have a, c_1, c_2, $g_{ij} > 0$, $i, j = 1{,}2$.

To attempt an operative use of the model, it is essential to use econometric measurements to determine all of the figures listed heretofore. If now R_1 and R_2 represent two conversion constants, which express the profit part achieved, reinvested to increase production, the evolutionary dynamic of the model is supported by a system of differential equations:

$$\begin{cases} \dot{x}_1 = R_1\left(\dfrac{a}{x_1+x_2} - \left(c_1 + g_{11}x_1 + g_{12}x_2\right)\right)x_1 \\ \dot{x}_2 = R_2\left(\dfrac{a}{x_1+x_2} - \left(c_2 + g_{21}x_1 + g_{22}x_2\right)\right)x_2 \end{cases}$$

The mathematical analyisis of the model has been thoroughly examined in a recent research paper (Barbiroli and Ritelli, 1997).

Dynamic market conditions. We shall now present a generalization of the previous system, with the aim of mathematically analyzing the situation in which the economic availability by all consumers is not constant over time. We shall adopt the standpoint that this availability varies according to the entry on the market of the new technology. We feel it is important to emphasize the main limitation related to this model, as such an interpretative reading is possible only in the stages immediately following the introduction of the new technology: the increased availability of resources by consumers generated by the improved supply cannot take place over the medium-to-long term. Once past the initial stage, the market availability will return to being constant, although we cannot exclude the possibility of its returning to a higher level than before.

For the model we propose for this purpose, we start with the following formulation: let f:$[0,+\infty)\times(0,+\infty)\times[a_0,+\infty[\rightarrow\mathbf{R}^3$, be a continuous function, $f = (f_1, f_2, f_3)$ where $a_0 > 0$ represents the availability of consumers when manufacturer 1 enters the market, and:

$$f_1 = R_1\left(\frac{a}{x_1+x_2} - \left(c_1 + g_{11}x_1 + g_{12}x_2\right)\right)x_1$$

$$f_2 = R_2\left(\frac{a}{x_1+x_2} - \left(c_2 + g_{21}x_1 + g_{22}x_2\right)\right)x_2$$

$$f_3 = g_{31}\,log\left(1+x_1\right) + g_{33}\frac{a-a_0}{1+\left(a-a_0\right)^2}$$

Unbalanced market conditions. In this section we would like to generalize the model in order to interpret a situation typical of competitive markets. Let us suppose that at a particular moment, which we can set at time 0, manufacturer 2 is able to launch a new product on the market, or a line of new products, similar but in some way improved with respect to those already on the

market, which has the effect of increasing the number of consumers, and thus in the end the economic availability a. Let us also suppose that this increased availability of funds benefits solely the innovative manufacturer. It is of course necessary to insert a third equation to express the fact that the economic availability a may change, and since this change depends only on the intervention of manufacturers of the second type, we shall admit that this variation is a function only of the variable x_2. This market entry originates from "unbalancing" effects, because the increased market availability will benefit only the innovative technology, and could lead either to the extinction of the previous production technology or to its survival, but at a reduced percentage rate.

Such a situation appears to be interpreted by two models, where the previous annotation remains valid.

The first expresses an evolutionary situation in which the introduction on the market of new products generates a constant, but limited, increase in the amount of money available, while the damage suffered by old manufacturers due to the entry into the market of new antagonists is expressed by the introduction of a factor type $(1 + x_2)^{-1}$. We thus have the system of differential equations:

$$\begin{cases} \dot{x}_1 = R_1 \left(\dfrac{a}{1+x_2} \dfrac{x_1}{x_1+x_2} - x_1(c_1 + g_{11}x_1 + g_{12}x_2) \right) \\ \dot{x}_2 = R_2 \left(\dfrac{ax_{21}}{x_1+x_2} - x_2(c_2 + g_{21}x_1 + g_{22}x_2) \right) \\ \dot{a} = \dfrac{x_2}{1+x_2} + g_{33} \dfrac{a-a_0}{1+(a-a_0)^2} \end{cases}$$

The second model differs from the first only in the third equation, which in this case expresses a different evolutionary dynamic of the availability of money: it is supposed that the increase availability stops, after the initial growth, to return to a constant availability of money, which may be greater than the original level:

$$\begin{cases} \dot{x}_1 = R_1 \left(\dfrac{a}{1+x_2} \dfrac{x_1}{x_1+x_2} - x_1(c_1 + g_{11}x_1 + g_{12}x_2) \right) \\ \dot{x}_2 = R_2 \left(\dfrac{ax_{21}}{x_1+x_2} - x_2(c_2 + g_{21}x_1 + g_{22}x_2) \right) \\ \dot{a} = g(x_2) + g_{33} \dfrac{a-a_0}{1+(a-a_0)^2} \end{cases}$$

where:

$$g(x_2) = \begin{cases} x_0 x_2 - x_2^2 & if \ \ 0 \le x_2 \le x_0 \\ 0 & if \ \ x_2 > x_0 \end{cases}$$

In both cases, we have an autonomous system of differential equations of the type $\dot{x} = f(x)$ con f:$(0,+\infty)\times[0,+\infty)\times[a_0,+\infty[\rightarrow\mathbf{R}^3$ continuous.

In order to arrive at models that have a theoretical and concrete validity, a variety of market situations can be considered: from those in which the availability of money is constant to those in which such availability may increase.

The mathematical instruments used refer to the study of the stability of dynamic systems, according to the well-known theory of Liapunov (Verhulst, 1990; Tu, 1992). Therefore, since this model proceeds by linearization, the time horizon for verifying these models is necessarily limited. For the models introduced in this note, we have substantially emphasized the influence of production costs and costs due to competition — distinguishing between intraspecific and extra specific — on the ability of a technology to achieve success on these markets. The status variables are $x_1(t)$ and $x_2(t)$ number of products manufactured using the various technologies to which is added the variable a, expressing the market availability. The interpretation of the models in order to examine the possibility of technological coexistence, follows the following pattern: begin by using the model in a situation in which one of the two competing technologies is absent. This condition is expressed by a point of equilibrium for the dynamic systems, to which we refer as extreme points of equilibrium:

$$X \equiv \{x_1 = 0 \, ; x_2 = x_{20}\}$$

$$Y \equiv \{x_1 = x_{10} ; x_2 = 0\}$$

Three possibilities exist:

1. If X is stable and Y is unstable, over the long term the system will end in X: coexistence is thus impossible.

2. If X is unstable and Y is stable, coexistence is still impossible, and the system will end in position Y.

3. Both X and Y are unstable. This is without any doubt the most interesting case: since a fixed division of the market — without specific agreements — is also unstable, periodic oscillations will occur so that a momentary increase of x_1 will correspond to a decrease in x_2, and vice versa. From a mathematical standpoint, this configuration is called a limit cycle. Although, as we have already pointed out, a regimen of periodic oscillations affects a theoretically unlimited period of time, while one of the basic points of the present models was that the analysis referred to the medium-short term. In practice, an oscillating regimen contradicts the strategic aims of all manufacturers in the market, so after a certain period some or all will take measures aimed at stabilizing the situation. In analytical terms, this means that some of the parameters will be changed.

The quantitative estimate of the model parameters deserves a separate chapter, especially for the coefficients g_{ij}, which as we have seen are determining in how they affect the system dynamics. It should also be pointed out that R_1 and R_2 — which, one will recall, take into account the reinvestment policy enacted by the various manufacturers —are not relevant in determining stability. However, they do condition the speed of evolution of the system once instability has occurred.

In any case, however, the situations studied in this issue refer to particular simplifications of real life: the models presented here consciously neglect a few aspects, specifically:

i) All of the economic systems illustrated are *closed systems*, in the sense that external factors are not considered: competition is adjusted only by the costs sustained by the game participants. Logistical aspects: distribution, ease of conservation, etc. do not interfere with formulating the models.

ii) The problem of the *protected market* has not been examined, which condition is quite widespread in reality, where some game participants are given certain advantages such as political-fiscal and financial privileges.

iii) The resistance encountered by a technological innovator when the new technology must face activities induced by existing technologies, and dependent upon them, are not considered; thus when we have complex production systems with synergism.

iv) No account has been taken of *technological compatibility*, which may also limit the success of a new technology.

v) No *optimum* analyses have been made, from the standpoint of either costs or yields, when introducing the new technological situation. As far

as these aspects are concerned, we will attempt a study using optimal control techniques.

All of these notes serve to point out once again the old scientific matter of modellistic analysis of reality. The complexity of an evolving economy is such that it does not allow a unitary treatment of the phenomena that occur within it. Any model, no matter how sophisticated, can never be able to describe reality exhaustively. Thus each individual model attempts an analysis according to a particular viewpoint, to then compare the results obtained with various instruments relative to the same concrete situation.

Chapter 9

TECHNOLOGY POLICY FOR SUSTAINABLE DEVELOPMENT

9.1. TOWARDS A SCIENCE OF TECHNOLOGY POLICY

It is well recognized that the objective of technology policy must be not only to develop a *systemic* set of *selected* industries in the capital-producing sector, but also to promote an *appropriate* class of techniques. The central task of all those involved in the process of technological development is to build what may be called an "integrated technological niche" as an essential framework for innovative activity.

It is sometimes argued that the most modern techniques, having survived the process of selection, are also the most efficient ones. This is the viewpoint of technological determinism: the scope for the choice of alternative techniques tends to be inherently limited because there can be only one optimal trajectory of innovations. The proponents of this thesis maintain that there is no viable alternative to the advanced capital-intensive techniques developed in the industrialized world.

There are actually two main criteria of success in technological innovation. The first criterion concerns the adaptability of technology to its task environment. This is essentially a consideration of whether the chosen technique is appropriate to its task. The second criterion concerns the adaptability of technology to the emerging production possibilities. This is essentially a consideration of whether the technique is amenable to modifications and upgrading through learning. Contrary to the generally held view in the literature, all other criteria, such as the labour- and capital-intensity of a technique, are of secondary importance in determining its technological innovation potential.

Thus it seems apparent that there are virtually no restrictions on the range of technological choice. The essence of technological progress does not lie in the singularity of the initial choice. Rather, it is the irreversibility of the consequences. Artefacts do not evolve of themselves, but human beings do.

This is not to say that innovations occur in a totally accidental manner. Indeed, many investigations reveal that there are a number of significant regu-

larities in the process of technological innovation. However, they also indicate that these regularities are themselves outcomes of what are essentially stochastic processes. Nature does seem to abhor a vacuum, as is commonly recognized. However, it is not pre-programmed to do so and it needs the setting up of sustainable conditions. The potential for technical progress is always there. Whether it can in fact be tapped is a matter of deliberate policy.

This brings us to the following conclusion: as technological innovation is a strategic factor of economic development, mainly in the context of sustainable development, what is needed is a science of technology policy, in order to provide the greatest number of alternatives.

9.2. SETTING INDICATORS OF SUSTAINABLE DEVELOPMENT

New indicators are proposed here to identify the parameters that contribute to defining the sustainability of development and, consequently, the intensity and limits of technology application. These values are to be considered useful indicators, below or above which development is intolerable, with all the inevitable consequences. The most widespread indicators mainly refer to the environmental aspects (Vos et al., 1985; Hueting et al., 1987; Uno, 1989; Opschoor et al., 1991; Daly, 1988; Van den Berg, 1996); it should however be considered that the use and diffusion of technology cause complex effects, differentiated among various spheres of the economy and the civil life of the society, and which contribute to evaluate whether or not the development is sustainable: employment, nutritional levels, urban population density, quality of development, resource depletion. While it is not particularly difficult to define the environmental indicators, considerable problems do arise in defining the indicators for all of the other aspects, as there is quite a difference among the various economic situations, as well as among the habits, mentalities and conditions of the various populations. Therefore, it is difficult to establish how to express a parameter, but it is just as difficult to define values common to all situations, capable of satisfying respective needs.

To this purpose a great effort has to be devoted to select the aspects which contribute to define "sustainability", and how to measure them.

The minimum or maximum values proposed, listed in Table 9.1, must be considered the basis for discussion, though several have been chosen on the basis of realistic considerations (Barbiroli, 1993b).

TABLE 9.1. Summary of the proposed indicators

1) Resource indicators

Resource Depletion

Energy resources Mineral resources	zero global balance between used and produced resources over a 10-year period

Environment

Air

	Maximum allowed values
CO_2	300 mg/m^3
NO_X	200 μg/m^3
Hydrocarbons (hexane)	200 μg/m^3
Photochemical oxidants (O_3)	200 μg/m^3
Total suspended particulates	150 μg/m^3
Free crystalline silica	0.01 mg/m^3
Pb	2 μg/m^3
Other heavy metals	100 μg/m^3
SO_X	80 μg/m^3
H_XS	10 μg/m^3
HCI	5 mg/m^3
HF	20 μg/m^3
Cl_2	0.3 mg/m^3
Dioxin	0.05 μg/m^3
Short half-life radioactivity (I_{131})	2x10^2 pCi/m^3
Long half-life radioactivity (Cs_{137})	2x10^3 pCi/m^3

Water

	Maximum allowed values	
	For civil use	*For Industrial use*
BOD_5	5 mg/l	40 mg/l
Total coliforms	absent	20,000 MPN/100 ml
NH_3	0.5 mg/l	10 mg/l
Nitrates-Nitrates (as N)	22.2 mg/l	10 mg/l
COD	5 mg/l	160 mg/l
Surface-active agents	200 μg/l	2 mg/l
Pesticides	0.5 μg/l	0.15 mg/l
Fertilizers (P)	0.5 mg/l	0.5 mg/l
Suspended solids (SiO_2)	absent	80 mg/l
Toxic metals and non-metals (As, Cd, Cr, Hg, Ni, Pb, Zn, Cu)	200 μg/l	3 mg/l
Alkalinity (HCO_3)	30 mg/l	150 mg/l
Specific conductance	400 μS cm^{-1}	1,000 μS cm^{-1}
Chlorides	25 mg/l	1,200 mg/l
Fluorides	2 mg/l	6 mg/l
Solvents	10 μg/l	0.3 mg/l
Phenols	0.5 μg/l	0.5 mg/l

Soil

	Maximum allowed values
Pesticides	0.5 ppm
Phosphates	0.5 ppm

TABLE 9.1. Summary of the proposed indicators (*continued*)

	Maximum allowed values	
Toxic metals and non-metals (Cd, As, Cr, Hg, Ni, Pb, Zn, Cu)	200 ppm	
Fluorides	2 ppm	
Forest Land (surface area covered with forests)		
	Minimum required values	
Flat areas	temperate	10%
	tropical	60%
	sub-tropical	40%
Mountain areas		30%
Noise		
	Maximum allowed values	
Factories (Internal)	50 dB(A)	
City Roads (External)	40 dB(A)	
2) Economic indicators		
Unemployment levels		
	Average annual income per capita	*Maximum % of total work force*
	up to $5,000	6
	from $5,000 to $20,000	8
	over $20,000	10
Nutrition levels		
	Minimum per capita per day	
Calories from carbohydrates	1,500	
Calories from fats	500	
Grams of animal proteins	50	
3) Social indicators		
Urban population density		
- Residential density (N° of people resident per km^2)	5,000	
- Working density (N° of working people per km^2)	10,000	
- Minimum open space available in the metropolitan area with respect to total surface area	20%	
- Minimum open and covered space aimed at recreational activities	10%	
- Time to arrive at and return from the workplace (maximum daily time, using any means)	60 minutes	
- Maximum time to travel one kilometer of city roads using private means of transportation	2 minutes	
Transportation Safety		
Maximum annual number of accidents causing personal harm for each type of vehicle in circulation	automobiles	0.1
	motorcycles	0.1
	trains	0.1
	airplanes	0.1

Resource Conservation. Given that the earth may no longer be considered a "treasure chest" from which to take illegitimate advantage of resources — especially those for the production of energy — either technology is capable of making new "artificial resources" available without disturbing the "natural resources", or technological change must be slowed down if not stopped entirely.

Already the current situation — and its relative trends — is to be considered worrisome, or even alarming, also because a number of non-renewable resources, energy and non-energy, are poorly used. Just think of the fact that all solid, liquid and gaseous hydrocarbons are burned with low efficiencies even though they are truly scarce, even from a dynamic standpoint.

One could adopt the hypothesis of defining a "steady state", as described above, in the sense of "dynamic equilibrium" between resources used and resources produced, within their globality. Among other things, the steady state criterion may also be adopted in setting the upper limits of the air, water and soil components (Opschoor and Reijnders, 1991; Liverman et al., 1988).

The basic concept is the "regenerability" of the resources as a whole, by using technologies capable of reproducing them, though at times with characteristics that differ from the "real thing". One significant example is the production of synthetic hydrocarbons to replace natural ones in organic synthesis for the chemical industry, and another is the production of heat and electricity — for various uses — with new systems, and thus avoiding the use of hydrocarbons.

Another emblematic case is the production of heat through uranium fission, in breeder reactors, in which the amount of energy actually obtained is much greater than the potential of the original uranium, though the self-fertilization time is approximately 10 years.

Also the use of metals such as iron, aluminium, magnesium, lead, titanium, manganese, copper should be subject to virtually complete substitution and/or re-use and the use of (conditionally) renewable resources — within a specific area and time span — should not exceed the formation of new stocks (for instance, yearly extraction of ground water should not exceed the yearly addition to ground water reserves coming from rain and surface water).

Environment. For air, water and soil, the main priority is to define the maximum standards of the most significant components, which when exceeded signify an unsustainable situation. The setting of upper limits for chemical, physical or other effluents in the air, land and water does not pre-

sent any particular difficulty because the quantities that will not upset the ecological balance have been established and the "metabolism" of the various effluents is well known. This means that technological development can proceed until these limits are exceeded.

Forest land. This important aspect that affects the balance of the ecosystems, may be represented as the minimum surface area covered by forests, with the necessary distinctions according to climate zone. At least certain ecological, climatic and pedological situations must be distinguished: temperate zone, tropical zone, sub-tropical zone, mountainous areas.

Values, including signs, of indicators may be different depending on their geographical scope. Thus, for instance, although there is a loss of forests worldwide, violating the steady state criterion and thus presumably giving rise to a negative value for the sustainability indicator involved, particular countries may expand their forests, and this may be reflected in positive values for national sustainability indicators.

Noise. It is necessary to separate the maximum noise levels allowed inside factories from those in city streets.

Employment levels. Another parameter to consider is the maximum "tolerable" level of unemployment in a given socio-economic system. For obvious social reasons, the lowest possible levels of unemployment are to be hoped for, but it is equally obvious that technological developments and the consequent economic changes will lead to unemployment. It might be difficult to establish a maximum "tolerable" limit of unemployment because there are numerous variables involved, some of them quantifiable and others not.

The maximum percentage sustainable by each economic system with respect to the overall number of the active workforce must be differentiated according to different income levels. This is because technology creates increased unemployment as it gradually contributes to achieving higher levels of development and wealth.

Nutrition levels. In relation to the minimum requirements of the population, it is necessary to establish a minimum threshold in the quantities of foodstuffs actually available on a day-to-day basis in order to adequately nourish each person, by taking various differing requirements into consideration. Although this approach sets a real limit to population growth, it does not do so in absolute terms but rather in terms of the real food-producing capacity of the economic system and its related production techniques. The setting of a minimum daily (or annual) threshold of foodstuffs does not present great difficulty, as data on food requirements are available. The values

may be expressed in terms of the number of calories available per person per day, from sources of carbohydrates, fats and animal proteins.

It goes without saying that the values should be adjusted to take into account different populations and conditions.

Setting minimum levels already includes adaptation of the technical, production and distribution potential, which have always conditioned the actual availability of foodstuffs for many populations.

Urban population density. Various indices can make it possible to establish the maximum size of urban areas and their qualitative organization: the maximum number of inhabitants who live and work in a square kilometre, the maximum number of open spaces (aimed at various activities) with respect to the overall surface of the metropolitan area, the maximum time required daily to reach one's work place and return home, the average time required to travel one kilometre by private means of transportation, inside and outside the city. Setting these sustainability indices means that whenever they are exceeded, large urban population areas must be radically — though gradually — changed until they reach the set values.

Technology must also be used to change the ways and means of transportation in order to reduce the travel times to the set levels.

Transportation safety. This important aspect may be quantified by setting the maximum limits of the number of accidents annually that lead to personal harm for each type of transportation means (automobiles, motorcycles, trains, aeroplanes). Technology can be especially advantageous to such a significant aspect of the social organization of any country.

In each economic field, the technologies to be chosen and adopted must have the characteristics necessary to satisfy the stated requirements. Consequently, development would be subject to strict conditions, but not to quantitative limits, and this is particularly important in view of the inevitable increase in world population.

As already specified, some of the proposed values seem to be acceptable, because they are the result of well-known studies and elaborations (resource depletion, environment, nutrition levels); others have to be considered mere hypotheses, to be discussed in depth (for instance, unemployment levels, urban density, transportation safety).

However, it must be emphasized that the set of constraints cannot identify an "empty set of opportunities"; on the contrary, during transition it is necessary to establish — through political choices — the way to bring technology back to the observance of all the indicators of sustainability.

9.3. GUIDELINES FOR THE TRANSFORMATION OF ECONOMIC ACTIVITIES

Economic activities in all countries must develop and improve with careful consideration of the events occurring in recent years world-wide, as a consequence of the repeated leaps in petroleum prices and of all non-renewable raw materials. In particular, on the one side the decisions made by many developing countries to start ambitious development programmes, including the original conversion of many raw materials, must be considered; on the other side, we must also consider the significant changes under way in the most active and dynamic industrialized countries (USA, Japan, Germany, UK, France, Canada) in all branches of activity, which already allow us to identify a new — and impressive — technological and industrial revolution in terms of production, quality and structure.

The plans of many developing countries mainly concern starting up or intensifying traditional productions, with a low-to-medium technological content, and thus added value; the changes in industrialized countries tend to increase the productivity and technological content, thus improving and qualifying all productions.

In these conditions, the international competition on many products will inevitably increase, as are the commitments by the most dynamic foreign companies (Mowery and Rosenberg, 1989).

To further complicate the emerging framework of the new international division of labour we have the co-operation and integration agreements between industrialized and developing countries to increase guaranteed supplies of raw materials.

These observations must mean that the choices for restructuring current economic activities be scheduled in order to be able to both sustain international competition and to sustain the economic development.

In the latter instance it is a matter of identifying the procedures or new branches of activity most appropriate, also in terms of the economic and social needs of the country. It is unlikely that each country can follow a model similar to that of the others in order to consolidate its international presence; it is more convenient and easier instead to develop its own model, allowing it to emphasize its typical national potential.

An effective development-improvement transformation must follow the following lines:

1) it must be considered a continuous and permanent process of revising the type of productions, processing systems and production structures, since

it must provide companies with increasing competitiveness within a socio-economic role, and within the targets of a sustainable development;

2) it must be a process to upgrade the value of raw materials (including energy resources) in a way to gradually reduce their incidence on the final value of products and services (Barbiroli, Raggi, Fiorini and Mazzaracchio, 1996) and to stimulate advantageous innovations in the production processes to achieve new global efficiency levels (Barbiroli, Raggi and Fiorini, 1996);

3) it must contribute to realize economic systems shaped in a "closed-cycle" form rather than in an "open-cycle" form;

4) it must be a way to achieve growing qualification of the companies, of the products and the workforce;

5) it must be a process of revising not only the productive sectors, but jointly the primary sector, advanced services and, especially the public administration and its instruments, also for the purpose of overcoming the productivity-employment dilemma from a strictly sectorial standpoint;

6) it must be characterized by investments selected according to qualitative and not merely quantitative criteria (thus soft technologies, organizational-managerial innovations, marketing and sales, technical service, research and development, design, and others);

7) it must be set up as a way to gradually overcome the imbalances between strong and weak areas, especially through a polycentric policy and the adoption of appropriate production systems and technologies;

8) it must be conceived as a process to make the overall economic system more flexible, increasing the "incoming" and "outgoing" job mobility.

It is not difficult to foresee that, in any case, it is a priority to make a "qualitative leap" in all company functions in order to create products able to satisfy the growing needs of international demand in terms of performance, practicality and cost.

Within this framework, the technological and organizational potential of companies and of the national economic system must be completely expressed and transferred to industrial production.

It goes without saying that if this potential is weakened, either due to neglect or other reasons by the public or private sector, it will be necessary to recreate the conditions for them to be brought to the necessary levels. We are referring, for example, to the ability of producing inventions, innovations and very high managerial and professional qualifications, to the ability

of the public administration to truly serve industries, and to the ability to penetrate international markets.

The above reveals that a policy of reorientation and improvement cannot be founded solely on choices dealing with industry in a strict sense, ignoring the problems of promoting and developing many service industries, which have become increasingly functional for industry and increasingly affect the success of production system re-conversion.

With this arrangement, new employment prospects can also be opened up, to compensate for the unemployment that comes about and inevitably arises in industry.

9.4. TECHNOLOGICAL FORECASTING AT THE DECISION-MAKING STAGE

The topics discussed in previous chapters show the need for an in-depth knowledge of technological dynamics in order to more easily achieve the policy-scheduling objectives set by each country and company.

From this standpoint, technological forecasting takes on a fundamental importance, in the sense of a method for predicting "if, how and when" specific solutions can be achieved.

In concrete terms, it may be defined as a probability assessment of future technological breakthroughs.

As we gradually proceed towards a sustainable development, if we can predict — and thus schedule — "how and when" certain production results can be achieved, or "how and when" certain resources not currently usable or reachable can be used and reached, it will be that much easier to predict — and thus schedule — the desired economic and social results.

For example, the use of non-traditional resources, now impossible, may be forecast at sooner or later dates: petroleum located in non-traditional deposits (oil shale, tarsands), minerals under the sea floor, etc. What we have said is not meant to imply that any result can be achieved through scientific and technological progress, but in light of the experiences and results achieved thus far, we can look more serenely towards the future.

The methods and techniques for technological forecasting are numerous and complex; they are commonly indicated as *brainstorming*, the *Delphi technique*, *extrapolation of temporal series, morphological research, block diagrams* and others, for which it is not appropriate to go into technical detail in this book.

It is merely necessary to specify that there are two, substantially opposed attitudes as to how to observe technological evolution, which manifest themselves in *exploratory technological forecasting* and *normative technological forecasting.*

The former considers invention to be a manifestation of an evolutionary process in the system, considering the future as an extension of the present according to current trends.

The latter instead places, at the foundation of invention and innovation, a human need that must be satisfied, and recognizes the needs of man as the true driver of technological progress.

Basically, exploratory forecasting is aimed at opportunity, while normative forecasting is aimed at a goal.

Within a framework of growing economic and social turbulence in industrialized countries, normative forecasting has taken on increasing importance since the late '70s, since exploratory forecasting must be based on certain elements, which no longer exist.

In normative technological forecasting, a specific method known as the "significance tree" is often used, according to which it is necessary to draw up a complete list of the technologies to be developed, the means required and the research to promote in order to achieve a general objective (Martino, 1992; Henry, 1991).

This is to define the path leading from the current situation to the realization of the set goals.

The elements to be considered are placed at different levels in relation to the different importance they have within the programme.

We thus have the first level, which is the general objective, beneath which is the second level, including the various operative areas; the third level contains the individual technologies required for each operative area and so on.

The result is a particularly complex structure which has the form of a block diagram, or genealogical tree.

Numbers of relative importance (or significance) in relation to the main objective are assigned to the items appearing in each level. The significance expresses whether, and how much, a technology or study is more important than the others in achieving the objective.

Technological forecasting is increasingly used, as mentioned above, for assessing in advance the chances of obtaining certain products or technological solutions within the foreseeable future.

Productions and goods of any kind may pass through a number of stages before achieving success, from discovery to commercial acceptance stage; from approximately 1700 to 1900, several decades could pass between the discovery stage and the commercial acceptance stage; currently, we find that this time has been considerably reduced for many productions, even down to 10–15 years. Technological forecasting can considerably shorten the times that pass between the first and third stage.

The various forecasting periods depend on the dynamics and trends that have occurred thus far; therefore, obviously, it would be useless to forecast beyond 5 years for consumer goods, and for the use of resources it would be useless to make short-term technological forecasts.

Technological forecasting is only a few years old. Its main value lies not so much in precision as in its contribution to planning strategies. The judgements expressed in this regard are based on old examples, typical of a premature stage, and are characterized by a lack of *systematic and complete analyses.*

These forecasts often reflect opinions, rather than studies: the consequences on the art of forecasting are catastrophic, since nearly everyone feels themselves capable of forming an opinion in this area. Often one is unable to resist "thinking with desires", and at times forecasting is considered as a means for impressing the public.

Another important difference between past forecasting and its current form is due to a change in the *nature of technological innovation and planning*, and also to a certain degree in basic research.

9.5. SELECTING AND IMPLEMENTING SUSTAINABLE TECHNOLOGIES

The emerging need for a sustainable development clearly outlined in Agenda 21, Rio Conference 1992, inevitably entails the development and implementation of great innovations in devising, designing, manufacturing and consuming goods, in ways enabling resource conservation, on the one hand, and employment levels increase and life standards change, on the other.

The new guidelines towards sustainability can be considered at the same time as restrictions and as innovation opportunities, this opposite view depending on the cultural background and sensitivity of the entrepreneurs implementing the possible options.

However, it is well demonstrated that if one considers the restrictions derived from resource depletion and environmental imbalances as a stimulus for

implementing new productive patterns, the enterprise can achieve improvements of the overall performance, and consequently can be more and more competitive (Barbiroli et al., 1996a and 1996b). This means the effective adoption of economic criteria consistent with prevention principles and with "closed-cycle" economic systems, capable at the same time, to make new technological pathways economically viable. In this sense, the main choices shall be based on the culture and practice of "re-producing", so as to spread the idea of "industrial metabolism" (Ayres, 1993; Graedel and Allenby, 1995).

These pathways basically seem to be the following:

- optimizing the life-span of durable goods;
- spreading eco-compatible production technologies;
- reducing the incidence of materials and energy in the final value of goods (dematerializing of industry);
- devising and developing eco-compatible materials;
- designing and implemeting eco-compatible energy-systems;
- enhancing eco-compatible techniques to increase availability of agro-food and agro-industrial resources;
- developing advanced techniques to increase the availability of water for civil and industrial uses.

In order to optimize the life-span of durable goods (life extension, proper and cost-effective use, in the context of the whole life of the products) new criteria in designing and manufacturing should be adopted in a way to enable their upgrading/development, repair, reconditioning, reuse, recycling.

These conditions can be accomplished through modular design, in which a product is conceived as a combination of modules, each of them easily replaceable with others, new or refurbished, leaving unchanged the basic structure (computers and some aircraft are clear examples of the life-span optimization/extension); but they can be also accomplished by realizing and selling "functions and utilizations" in place of single goods.

Designing goods with new functional characteristics means preparing a new overall design, in which qualitative features prevail. In other words, the design of the goods must derive from a re-evaluation and revision of qualitative features.

Thus, returning to some of our previous examples, if the "functional" qualitative features of an automobile for the year 2000 and beyond must be low energy consumption, physical duration, safety, comfort, easy maintenance, easy recovery-recycling of the materials, resistance to corrosion, then the choice of the type of engine, the materials to use, the external and inter-

nal shapes and sizes must be made in consequence, creating a type of vehicle in which these features are optimized with one another, at the same time satisfying the productivity and competitiveness needs of the company. This is certainly the most delicate aspect of a production re-conversion, in which new qualitative features must be developed which are — often, though not always — in contrast with current ones, but without neglecting the problems of productivity, management, and return on investments (for example, when it is necessary to include eco-compatible features) (Barbiroli, Fiorini, Mazzaracchio and Raggi, 1993).

There is no doubt that the current production structures have achieved a level of optimization between type of product and productivity, and this level has now been consolidated for years.

Changes in the current system may even cause considerable imbalances, on the very level of productivity and thus business economy. For these reasons, companies proceed cautiously with internal restructuring in nearly all production areas.

The design stage is undoubtedly fraught with difficulties, should one wish to strongly re-direct production in the predicted direction, because the factors involved in production vary in type, quantity and ratios (production coefficients). In other words, the different combination of factors for achieving new performance inevitably changes productivity, and more likely for the worse, since in all stages of the company greater commitment and organization for the quality of the product can slow down the production cycles.

In order to adequately place new goods, with new functional features, on the market, it is essential that they respond to the pre-requisites described above. Now, while it is true that this arrangement stems from the increasing needs of the demand, it is also true that there is no certainty that these new goods will be used on a sufficient scale to provide companies with an economic return and, especially, without creating "adaptation" problems. This is actually the most delicate and complex aspect of the problem, especially for intermediate goods (materials), whose application must be viewed within a complex system, in which no change or innovation in products or processes ever takes place *sic et simpliciter*, but requires direct adaptations and leads to other, induced innovations.

Of course such direction prompts new forms of innovation and of technological evolution, presumably very different from those implemented until now. We must highlight the inevitable slow down of the production rates for

nearly all durable goods, the equally inevitable modification of their economic significance, and the consequent modification of their utilization ways.

Moreover, these changes prompt structural transformations of whole economic systems, with an increasing importance of the service activities, which are needed for enhancing all the forms of technical assistance.

Great transformations are also expected by the further intensification of the dematerializing of goods and industry, by means of the increasing importance of non-material inputs and the coresponding reduction of incidence of material and energy in the final value of the products.

As a consequence of these trends, all activities supplying and related to R&D, design, management, marketing, technical assistance are destined to be enhanced, as well as new forms of intellectual and technical skills.

Setting-up and developing eco-compatible technologies is a fundamental breakthrough in achieving the aims of sustainable development, particularly in all branches of industry with high material, chemicals and energy intensity. High levels of environmental efficiency can be achieved by designing production processes and related technologies able to give remarkable improvements of all the manifold aspects of performance/efficiency, namely: materials, energy, environment, quality, flexibility, versatility, size, inputs efficiencies.

UNEP has arranged an international programme, started in 1993, all over the world, consisting of setting and implementing new clean processes, in different industries, in several countries, with a special emphasis on the replacement/elimination of hazardous compounds.

The results that have been achieved are very encouraging, both on the side of environmental efficiency of the processes and of economic performance of the investment. Some interesting results have been reported in Section 4.2.

Eco-compatibility is a fundamental feature in all production processes, and its achievement needs great efforts to be devoted to their implemenation and setting-up, starting from R&D and design.

The transformation of all production activities as a function of "closed-cycle" economic systems entails the devising and development of suitable materials, that is to say materials with advanced performances and, at the same time, with high eco-compatibility in all stages of production and utilization (i.e. repair, reuse, recycling, etc.).

The problems related to availability and conversion of energy sources must be considered the most difficult to be overcome, mainly because no suitable alternative solutions are available, both for technological and eco-

nomic gaps. The development of new energy systems — based on advanced technologies more than on natural resources — has met, and still meets, great difficulties and resistances, of different origin, and this slows down the transition from the traditional carbon fuels to non-carbon energy sources.

And this situation is particularly negative after the economic transformation of nuclear energy as a consequence of the raising implementation of safety systems in nuclear power plants.

Only few countries are devoting efforts and funding to set up and develop new energy systems, both centralized, as nuclear fusion, and decentralized, as solar energy and wind; but the moment of achieving the feasibility stage is still uncertain, and both developed and developing countries do not seem sufficiently aware about this basic necessity. Moreover, the low prices of oil, coal and gas cannot stimulate any substantial innovation enabling the transition to sustainable forms of energy.

It must be underlined that large water resources in several areas of the world are still unexploited, mainly as a consequence of the unidirectional efforts made by the industrialized nations toward nuclear fusion plants during the last decades. The major constraints to the enhancement of large-, medium- and small-sized hydroelectric basins, are distance from the places where electricity and water are used (which can be partially overcome by implementing long distance transportation systems), the strong realtionship between electricity and water supplies, the possible environmental damages of artificial dams and basins.

To avoid all these risks and to optimize production with utilization, huge amounts of funding and human resources are needed, especially for achieving appropriate technological and organizational solutions.

Since nutritional needs of the world population are increasing, increasing amounts of high quality and safe foodstuffs are required, but the current agricultural and processing techniques do not seem to be able to give substantial progress, but, on the contrary, the main treatments (fertilizers, pesticides, additives, etc.) give rise to irreversible damages. Biotechnologies can be the new possible technological frontier because of the great yield increases it can give in almost all produces. Biotechnology is already under great development and given much attention in several countries, but there is great awareness about the possible drawbacks related to a generalized implementation of biotechnologies.

These are the reasons — one positive and one negative — why this technological pathway must be carefully considered and enhanced, and it may be-

come a "leading edge" in sustainable development, but it may also become a weak point in cases of its generalized misuse (e.g. genetic manipulations).

In the field of renewable resources cellulose has become a basic raw material, but the damages linked to deforestation are well known; consequently, non-wood fibre plants need to be enhanced all over the world, and their cultivation must be inserted in the cycle of irrigated crops. To be easily utilizable in paper making, processes using cellulose obtained from non-wood fibre plants need some adjustment and progress, as well as processes transforming cellulose into chemicals.

The lack of water for civil, agricultural and industrial uses has already become an unsurmountable barrier to any type of development, mainly in the southern hemisphere, but also in several regions of the northern one; therefore, desalination techniques are a way of increasing pure water availabilities, but the energy factor is a remarkable linkage in the large plants (multistage flash desalination, multipurpose plants, reverse osmosis, etc.).

This constraint may be overcome only by means of a well oriented technological progress, together with organizational improvements.

In some areas of the world the huge and regular availability of pure water can be economically exploited both for electricity and water supply by building up large-, medium- and small-sized dams and basins (Africa, Asia, Russia, South and North America), of course only after the environmental and social impact assessment has excluded the rise of irreversible drawbacks.

9.6. PURSUING A REAL TECHNOLOGICAL PLURALISM AS A FUNDAMENTAL CONDITION FOR SUSTAINABILITY

Since the '80s, the trends in all branches of manufacturing industries are towards an increase in product diversification, which basically can be obtained by means of flexible and versatile manufacturing systems. But these trends cannot be automatically considered consistent with a sustainable development in the interest of consumers, especially if, to get a wider range of quality diversified products, great investments in R&D, design, manufacturing, management, marketing and technical assistance are required from companies, and they lead to increasing production costs without a corresponding benefit (quality and/or productivity increase) for consumers.

This unsatisfying benefit/cost ratio of production options and trends contrasts with the need for a real "technological diversification" (plurality of alternatives to get equivalent outcome) of the ways to produce goods so as to enable appropriate choices to be made for achieving a maximization of benefits, as compared to costs, for companies, consumers and society (enivironment, resources, territory, employment, life-style standards). For instance, in the hydrocarbons sector no real alternatives to oil have been developed in the last two decades, as in the electricity field there is no real industrial alternative to thermoelectric and nuclear/fission power plants.

This does not mean that some product diversification within each process has not to be considered advantageous both for companies and for consumers, mainly if the ratios price/performance of the products are equivalent.

Indeed, at present, high price differences for slight or even illusory quality differences among the same line and type of products (automobiles, electric appliances, clothes, shoes, foodstuffs, etc.) may be checked; this mainly depends upon production reasons (additional cost for flexible manufacturing, advertising, technical assistance, etc.) and/or demand reasons (subjective quality factors, the status symbol and market distortions).

Of course, if one considers the aims and requirements of sustainable economic systems, it is nearly impossible to set, for each good, the "optimal" degree of diversification both for companies and for consumers, whilst it is fairly easy to measure and assess the objective quality/performance characteristics of goods.

On the one hand, an excessive and artful, possibly marketing driven, diversification/flexibility often alters the real needs of consumers and population; moreover, it needs additional resources, funds, management that, consequently, increase the production cost and, at the same time, are taken away from other priorities, such as the basic modification of all production criteria, consistent with sustainability (type and characteristics of products, cleaner production systems, etc.).

On the other hand, prices increase — above all those of basic goods — reduces the purchasing power of citizens and their attitudes toward goods and services.

This situation, in conclusion, prevents the new principles for sustainability from being pursued and realized; above all, it averts the development of an increasing number of possible alternative production solutions in the same fields of activity, technically and economically viable, so as to enable

the most appropriate to be selected and implemented, in different environmental, economic, territorial and social situations.

9.7. A NEW ECONOMIC HIERARCHY OF TECHNOLOGIES AND PRODUCTS

We must now highlight the fact that devising, developing, implementing and spreading new production technologies, appropriate to pursue sustainable development, as well as obtaining artificial materials, chemicals and energy able to contribute to gradually achieve a "steady state" of material resources — ecological systems included — entails the achievement of certain economic results. These are very different from the present ones, starting from the type and features of goods and services, ending at their price and, consequently, their economic importance in the economy. This is a fundamental point to realize the great transformation that will take place when starting a sustainable development. As a matter of fact, it is not difficult — even not exactly quantifiable — to foresee that both the global incidence of each type of good in the whole economy and in the purchasing power of each family are bound to change.

If costs and prices of the new goods produced in compliance with "closed-loop" economic systems are respectively lower or higher than they are now, and if the total amount of these produced goods is higher or lower, both the above mentioned economic aspects might be very different from now. For instance, the adoption of "sustainable criteria" in manufacturing durable goods (household appliances, automobiles, computers, aircraft, air-conditioners, machinary for agriculture, etc.) will considerably entail their life-span extension; in other words, their demand will dramatically slow down and their global production volume will be reduced. As a consequence of this, manufacturing companies shall shift their focus from selling goods to selling "functions".

At the same time, sustainability requires the enhancement and development of goods-services (such as high energy and material efficient transportation means), as a whole.

The consequent modification of the inputs structure in adopting new criteria — which is also taking place as a consequence of the dematerialization trends — might lead to the modification of their economic significance.

First of all, the changing utilization and demand of all raw-materials and energy forms will inevitably induce great transformation of the economic, as well as the political, situation of the raw-materials markets.

For instance, if new energy systems could gradually replace for the traditional sources of energy (oil, coal, natural gas), in a way to enhance the "decarbonizing process" of the economy, a new economic hierarchy will take place where some energy sources/forms — and related technologies — dercrease, some others increase, both as an absolute and a relative value.

9.8. CONDITIONS AND INSTRUMENTS TO GUIDE TECHNOLOGICAL CHANGE

The evolution of technology can follow different paths, and produce results that are just as varied, even with a prevailing number of negative effects. Since neither rigid planning nor technological determinism are convincing, once the confines of development itself have been determined, in order for it to fall within the framework of *sustainable* development, the path that seems most advisable and easiest to travel is to create conditions and adopt instruments capable of guiding and managing technological development.

The conditions and instruments are partly the responsibility of government authorities, partly of public or public-private institutions, and partly of private companies and initiatives.

A government, and the entire public sector, can exert a considerable influence on technological dynamics and consequently on development and improvement of production activities, directly or indirectly. There are a number of conditions that may be created and instruments that may be adopted in this direction (Barbiroli, 1996c). The main ones are:

- to establish an international and domestic political and social stability;
- to adopt international co-operation agreements;
- to adopt specific intersectorial and territorial programmes;
- to provide public enterprises with a stable and active planning function;
- to qualify the functions of the Public Administration;
- to enhance the supports for technological research and innovation transfer;
- to adopt specific laws;
- to strengthen the organization for professional training and retraining (upgrading);

– to prepare specific funding;
– to use the tax instrument in a corresponding, specific manner.

Certain major considerations must be made for each policy.

Political and social stability. This is certainly the primary policy to adopt in order to encourage businessmen to restructure and reconvert according to the desired directions and to systematically travel along the path of technological progress. Indeed, only in a situation of certainty can investment yields be calculated (Ackroyd, et al., 1992).

However, it should be specified that stability must not be confused with immobility; stability must be considered as a situation in which the rules of social behaviour are predetermined and controlled, especially those relating to industrial relations and public services.

The businessman, aware of these behaviours in advance, is able to plan his choices, inserting well-quantified exogenous parameters among the endogenous ones.

Only in this way can one lay the foundations for a new stage of economic development, in which company positions can be strengthened as well as that of the country from an international standpoint, and at the same time creating a better balance among social actors.

Specific intersectorial and territorial programs. The transformation of production activities and, consequently, the adoption of new technologies may be carried out only with an intersectorial view and, moreover, within a specific territorial context. In fact, each transformation introduced into a company produces economic effects on all of the activities in several related sectors, and particularly in specific areas where the activities are more closely linked.

Therefore, intersectorial and territorial programs must be elaborated and adopted, mainly with the contribution of the government and the public authorities which have a direct political and economic responsibility, in order to give specific directives that shall be transformed by the companies into application.

This instrument becomes particularly effective when the economic importance of a production activity must be reduced or improved as a consequence of a reduced or increased demand, respectively.

International co-operation agreements. A new, active international policy must establish stable political and economic relations, through continu-

ing forms of co-operation, which create real interdependency and integration; in other words, the various contracting countries must be integrated together so that each has an interest in continuing and intensifying relations in order to achieve its own development choices, each contributing according to its own potential and vocation.

Each government has the increasingly complex task of laying down the conditions for the above interdependency-integration by stipulating multilateral agreements that overcome the traditional transfer of raw materials and technology. These need to include the participation of national companies — private or public, individual or associated, medium-sized or large — in realizing the aims of those very countries by setting up, managing, and maintaining companies and services; but they also need to include the participation of companies from those countries in initiatives within the country, in sectors and according to methods that will be specifically defined during the concrete development stage (Office of International Affairs, 1992).

Within this context, for example, those countries that have ample reserves of traditional energy resources (natural gas, petroleum, coal, uranium minerals, water resources) or considerable potential for non-traditional resources (oil and tar sand and silt, geothermics and others) will contribute to economic development by providing these resources. Co-operation can also be developed in the area of research, extraction, on-site conversion and transportation of these resources. There is thus no doubt that extracting large quantities of hydrocarbons from oil and tar sand and silt must take place on-site, and this requires the creation of special joint-ventures among companies from the various partner countries, which must however cover the long term and not expire quickly (Guertin, et al., 1993).

The most suitable forms of co-operation must be established in each instance, but must also include the scientific, technological and cultural forms of co-operation necessary to encourage the desired integration, while fully respecting individual social-cultural qualities.

Finally, government managers must work to create stable and positive economic and political conditions with current or potential producing countries. This type of political arrangement, aimed at creating interdependency and integration, appears to be the most suited for reducing — if not overcoming — the dangerous effects of fluctuating prices in the vicious circle: price increase – recession – reduced consumption – reduced prices – non-productive investments in other fields – economic recovery – price increase – international tension.

This line of international policy would also make it possible to stimulate increasing technological and managerial skills in the companies called upon to work in the supplier countries.

Public enterprises. If used correctly, these are a typical planned public intervention tool, which make it possible to define a new type of government involvement to provide company-owners with a new framework of reference and certainties; in other words, these should indicate which sectors to develop, how and where.

Of course, the main contribution of public enterprises should be in the types of products, the manufacturing systems and thus technologies, the type of production organization and marketing, in research and development of knowledge and information. Undoubtedly this has not so far been the case, in Italy; it is therefore essential to re-orient the criteria for managing public enterprises, emphasizing the function of orientation in the development stage and support in times of recession: thus, a true planning function.

Public Administration. The Public Administration — with its many branches — has taken on an increasingly important role in the economy of industrial companies; however, it has not always been done very efficiently and functionally, and often it has even become a delaying, negative element in running a company.

It is necessary to convert and modernize the Public Administration, which will become even more important in development and industrial qualification.

Support for research and technology transfer. The government must intervene to promote and sustain scientific and technological research through specific programmes, to be implemented directly through its own research institutions, or indirectly through independent private, specialized and qualified institutions, or industrial centres.

However, these programmes must be seriously co-ordinated and realized, so that the results achieved can become a concrete foundation for the technological advancement of industries.

For this reason, even serious and committed technological research is not sufficient if it is not accompanied by a policy aimed at transferring its findings to industry, both domestic and foreign (Loveridge and Pitt, 1992).

So it is especially important to create the conditions to make it possible and economical to adopt the new technologies arising from research.

Among the most useful conditions are: aid contracts in realizing inventions, special development contracts, financial assistance for new initiatives and for selling patents, information services for small- and medium-sized companies (Mowery and Rosenberg, 1989).

Legislation. Laws represent the most valid and perhaps most immediate tool for achieving the desired objectives, making changes and introducing the desired innovations — if applied. However, especially in Italy, valid laws are often not applied, or legislation is inadequate for modern society.

It is especially important from now on that laws aim to direct and control technological development and the diffusion of productions, either to avoid a number of problems or to facilitate achieving each economic policy (Arup, 1993).

Legislation such as the anti-smog law for fuels, or that regarding the construction criteria for private buildings, if operative, is able to change production orientations on the one hand and consumption on the other.

The same is true for laws about water recycling, limiting exhaust emissions, regulating extraction activity and, more generally, for laws that regulate production so as to make more or less important or radical changes.

Professional training and retraining. When reorienting the type of productions or production systems, in which the workforce becomes increasingly important, it is essential to improve professional skills.

Thus great care must be taken in organizing training, at all levels; the primary objective is to create diversified professional skills, capable of satisfying the need for mobility.

To facilitate the insertion of a worker in a new company, the "retraining period" should be introduced if necessary, which consists of having the worker attend courses for at least one year, supported by the company. This system — widespread in other European countries — should obviously replace the redundancy fund, which cannot be considered viable in a modern society, and would be a concrete contribution to the mobility of labour.

Credit and financing. In order to realize an industrial restructuring policy such as the one described above, ordinary and special banking institutions should significantly change the system and principles upon which intervention is decided. Intervention by these institutions should be regulated by truly "qualitative" principles; in other words, they should enter into the

merits of the investment, and take into account the potential ability of the investment to actively and positively enter a context such as the one outlined.

This can be done by carrying out feasibility studies, evaluating where the initiative falls in the specific intersectorial plans, the degree of qualification of the production, sales and marketing organization. In addition, by carefully assessing the company's ability to gather information on scientific, technical and organizational progress from outside — for companies that do not have such an ability from within — and the capacity to carry out independent research for companies that have this internal capability, in the form of research and development offices and centres. This is necessary because knowledge and information about the progress under way — in all countries — are essential within a context such as the one outlined.

There is no doubt that the functions required by a banking or financial institution are generally at a sharply higher level than those commonly carried out, which has been going on for some time in many industrialized countries.

Tax instruments. If used in a co-ordinated fashion with other instruments, especially financing, the tax instrument may be an excellent means for facilitating re-orientation and technological progress.

Already some countries (USA, Germany, France, for example) make extensive use of detaxation of companies that adopt new technologies to increase the productivity and qualification of their functions. Detaxation should be commensurate to the type of innovation and the role it has in the company's development.

Among all of those listed, this is the most immediate and incisive instrument for renovation.

On the other hand, it is also true for problems such as pollution: application of a tax commensurate to the marginal damage caused by emissions or other types of environmental disturbance would stimulate industries to introduce systems to eliminate or prevent the cause.

* * *

Now, it has to be emphasized that, in the context of the outlined conditions and instruments able to guide technological evolution and progress, a great effort must be made by all private and pubblic operators at establish-

ing "integrated places for innovation", able to give rise to original, continuing and effective "paths of innovation".

Indeed, as has been amply demonstrated above, in the presence of complex and costly modern technologies, it is no longer possible for companies to finance their own research and reasonably hope to be successful.

In order for the various forms of structures for innovation (industrial liaison and technology transfer centres, business and innovation centres, business incubators, scientific parks and technological poles) to be successful, they must provide the following basic features:

- mobilization of the most active resources of the university and research world;
- promotion of entrepreneurial spirit;
- emphasis on the ability to select potential entrepreneurs;
- creation of common activities between companies, universities and researchers (cross-fertilization);
- promotion of co-operation — in stable forms and structures — between private and public bodies, on common objectives;
- have new companies co-operate with successful companies;
- have top research centres, innovative companies and higher education institutions interact (triangle);
- development of liaisons with other technopolis elsewhere;
- creation of quality and flexible use of the areas, infrastructures and services available within the technopolis;
- attracting risk capital;
- interacting with local and national public authorities;
- constantly increasing professionalism at every level.

9.9. CONCLUDING REMARKS

Technology and its dynamics have always played a central role in all stages of economic development, contributes at the same time to produce wealth, but also to deplete natural resources and to disrupt ecological systems.

In the present stage of development, which started at the beginning of the '80s after the second oil crisis, and which is usually called "re-industrialization", technology, with different features and effects, is still playing a fundamental role in economic development, but it certainly is not yet consistent with sustainable development and many inconveniences are still apparent,

in addition to those already mentioned relating to natural resources depletion: unemployment, quality of life, distance between rich and poor countries, hunger.

This means that either technology is not appropriately implemented and managed in many fields of economic activity, or it has not yet reached a sufficient degree of maturity in several stategic branches.

Many of the inconveniences to society arise from choices made by manufacturing industries without considering the population's requirements, in a general sense, and without caring about the several negative effects on society.

Therefore, from now on, the main responsibility of governments, on the one side, is to establish guidelines, boundaries, advantageous conditions and economic policy instruments, to make it possible to develop and implement innovative and appropriate "society-oriented" (sustainable) technologies, able to prevent the formation of the current drawbacks; on the other, the main commitment of industry and all economic operators is to select and adopt technological options, compatible with and prompting a sustainable development.

To this purpose, the availability and application of reliable methods to evaluate ex-ante the economic advantage of technologies to enterprises and to society, in the perspective of sustainability, are fundamental conditions to reconcile the requirements of enterprises and society, as well as the increasing effort to pursue an oriented evolution, in a way to avoid the rise of undesired effects, at all levels (resources, environment, employment, hunger, quality of life, etc.). In this sense, all enterprises must become "sustainable enterprises".

This way is neither easy nor inexpensive, especially because starting a sustainable development, both in developed and developing countries, needs dramatic changes to be made in all economic activities and in consumption attitudes; for instance, the adoption of the "re-making" principles in manufacturing durable goods calls for the modification of design and property/performances, so as to enable the economic repair, reconditioning, reuse, recycling, upgrading and development. This revolution, in turn, leads to the modification of the general features of goods, their production cost, their price, therefore their economic importance. Of course, again depending on technologies and their evolution, some goods will have an increasing absolute and relative economic value, others a decreasing one.

The very intensification of the dematerializing process of goods and of industry entails profound transformations of economic systems and structures.

The main consequence of these changes will inevitably be a new economic hierarchy of goods and of consumption attitudes as well as of the utilized inputs.

In this context, first among inputs, the price level of all raw materials is destined to change, this event depending both on their relative abundance or scarcity, their utilization and efficiency in processes, and their technological replaceability. Again, some prices will inevitably rise (e.g. oil and natural gas); some other, will fall.

Also the diffusion of eco-compatible (cleaner) production technologies, could lead to an improved overall processes efficiency, to the modification of the structure of the inputs and to the achievement of new technological and organizational frontiers, of course consistent with sustainability.

Since hunger is one of the main concerns today, and since the current cultivation/processing techniques of foodstuffs cannot easily increase productivity levels, biotechnologies are commonly considered the most actual alternative option both in developed and developing countries, but the selection and development of some of them give worries about the possible negative impacts on human health and the environment, first of all the genetic manipulation.

Consequently, all efforts must be made to avoid, as far as possible, the risks connected with such worries; therefore, the application of methods for previous techno-economic evaluations of features, behaviours and impacts of technologies is all the more essential.

It must be emphasized that if all concerns about resources, energy and environment are considered by enterprises as constraints and restrictions, able to reduce their field of action, all choices that are needed at all levels will be delayed or even produce negative effects for all actors; on the contrary, if they are considered a stimulus to develop and implement new global innovations, economically viable and advantageous both for enterprises and for society as a whole, the route toward sustainability will be easier and cost-effective.

As a final conclusion, we may stress the need for all societies willing to enter the era of sustainability, of "closed-cycle economic systems", of resource conservation, to devote great efforts to establish new enterprises appropriate to such type of economic, social and cultural development; notably, the so-called "service-enterprises" which are both enterprises able to fully contribute to "close the cycle" and enterprises prompting the desired technological change.

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